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CLIMATE CHANGE AND EXTREME EVENTS: ALTERED RISK, SOCIO-ECONOMIC IMPACTS AND POLICY RESPONSES.

SUMMARY FINAL REPORT

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I. OBJECTIVES

Changing, and particularly worsening extreme weather and the possible relation to the enhanced greenhouse effect has raised considerable concern of public, policy makers and scientists, a concern fed by a series of record breaking natural disasters in the late eighties and early nineties. Questions raised include: Are these events signalling climate change? and, if so, what may a warmer future bring? what would be the impact? what are the vulnerable sectors and regions? who are the stakeholders? what are their options? and what would be a sensible response?

These questions have relevance in different policy domains. Greenhouse-gas emission policy should take account of the economic, social and political impact of weather disasters. Policy makers in areas such as property insurance, natural disaster reduction, long-term investment, and engineering face the prospect of changing return periods of hazardous weather, forcing them to alter their businesses under the threat of increasing losses. Potential responses shape to a large extent the actual damage, but are contingent on opportunities, perceptions, habits and available scientific knowledge. The present research project contributed to the process of adaptation. Its central objective was:

- to provide policy makers in international agencies, national governments, non-governmental organisations and the insurance industry with a state-of-the-art review of the potential impacts of the altered risk of extreme weather events due to climate change based on scenarios and an identification and evaluation of policy responses.

With respect to climate change, the basic assumption was a gradual change mean temperature and precipitation, in line with main stream expectations. Sudden and large changes are beyond the scope of this research.

II. METHODOLOGY

An extreme meteorological event, a wind storm or intense rainfall, does not necessarily prompt a natural disaster. Required in addition is an impacted object having a value to society. Therefore, subject to research were conjunctions of weather events and societal stocks and processes, in a particular place, at a specific moment and in a particular societal context. The contextual character of the topic of "extreme weather events" led to a case study approach. The working titles of the selected cases were:

- clay shrinkage-induced land subsidence and climate change in Europe;
- agricultural drought and climate change in Europe;
- European flood risk in a changing climate;
- heat waves in a changing climate;
- wind storms over Northwest Europe; and
- tropical cyclones over the Pacific Island Countries.

These cases were selected by taking into account their expected relevance across Europe, availability of data and specific methodologies for analysis. The case of tropical cyclones was chosen to illustrate the global dimension of the weather events issue, and to highlight differences in vulnerability between different levels of development. Also, it is agreed on in the Lomé convention that the European Union will assist small island states in the Southwest Pacific in the event of a natural disaster.

The implications of the findings of these case studies were assessed. Firstly, a considerable effort was made to study the role of insurance, in particular commercial insurance, both as a potentially vulnerable economic sector and as a mechanism for risk management. The research *inter alia* involved the development of a model of the insurance market, capturing climate change scenarios, the damages from extreme weather events, the behaviour of the market agents, market variables (insurer's policy instruments) and economic variables representing the macro-economic environment of insurance. Secondly, the economic impacts of natural disasters and natural disaster management were analysed and put into perspective. Economic accounts and investment behaviour were focal points. The third analysis across the cases aimed at characterising, from a policy sciences point of view, the policy problems that evolved from the research and how they could be addressed in the European context.

The research was structured in a three-step approach. The first step involved setting the stage, developing an overall systemic view on weather disasters, analysing and defining concepts such as vulnerability and natural hazard. This step also involved deciding on scenarios for climate change and population and economic growth. In the second step, the case studies were performed. Each case study assesses the impacts of changes in weather hazards, and analysed policy options to mitigate damage. The areas studied being so different, widely dissimilar models and methods were used. The third step involved the discussion of broader insurance, economic, and policy issues, and as reassessment the case-study results in these lights. In addition, the methodology was reconsidered.

Step one: Scope. The scope of the study was established in an international workshop. Much of the knowledge on climate change is embodied in General Circulation Models (GCMs). However, the strength of GCMs lies in their broad resolution in time and, particularly, space. Therefore, the derivation of case-specific scenarios on future incidence and intensity of extreme weather events (such as heat waves, droughts, wind storms, tropical cyclones and floods) requires expert knowledge and, in some cases, stochastic weather generators. The stock at risk is held constant in all but one case study. The final element of the scoping phase was the establishment of a common set of definitions for weather phenomena, impacts, policy options and responses.

Step two: Case studies. The case studies involved the following five elements:

1. The first element was a case specific, operational definition of the weather hazard. *Clay-shrinkage induced land subsidence* and *agricultural drought* are measured by a sustained water deficit. *River floods* are indexed by flood depth. These three hazards result from unfavourable combination of the spatial and temporal pattern of precipitation and temperature. *Heat stress* was measured by the length of the period with high temperature and humidity, in combination with time in the season, the diurnal cycle, and the build-up of the hot spell. *Wind storms* and *tropical cyclones* are indexed by the spatial pattern of wind speeds.
2. The second element was the identification of the direct impacts of extreme weather events. *Subsidence* damages buildings. *Drought* results in diminished crop yields. The impact of *river floods* was measured in economic damage done. *Heat stress* regards human health. *Wind storm* damages buildings. In the case of *tropical cyclones*, casualties, property damage and economic impacts were considered.
3. The third concept was the hazard-loss relationship between the exposed stock and the extreme event. *Subsidence* damage was considered by a descriptive analysis of drought, soil, and insurance claims. The impact of *agricultural drought* was assessed with a variant of the Erosion-Productivity Impact Calculator (EPIC). This process model described crop growth as a function of amongst other temperature, water availability, and atmospheric carbon dioxide. *River floods* was modelled by a simple empirical relationship between flood depths and property damage. The impact of *heat stress* was considered by a simple empirical relation between a physiological index and hospital admissions. *Wind storm* damage was modelled by a simple empirical relationship between wind speed and the economic damage. In the case of *tropical cyclones*, no explicit relation between intensity and impact was considered.
4. The fourth element involved the construction of scenarios for the risks. This involved the conjunction of the weather scenarios and the hazard-loss relationships.
5. The identification of policy response options was the final step. It was based on literature research in the areas of (natural) disaster reduction, agricultural management, disaster economics, development economics, insurance economics, risk analysis, and policy sciences.

One of the case studies was different: it was a concise 1000-year history of flood management in the flood plain of the river Rhine in The Netherlands. This study illustrated and clarified concepts used and results obtained throughout the rest of the research.

In summary, in the case studies, a wide variety of methods was used, including the application of GIS-techniques to handle spatial information related to land use (agriculture), type of soils, distribution of wind speeds and stock-at-risk, and various statistical techniques to describe, analyse and model data.

Step three: Perspective. In the third part, the results of the case studies came together in a study of the weather insurance industry under climate change, an economic analysis of weather disasters, and an evaluation of policy response, and a reconsideration of the methodology employed.

The impacts on insurance - a major element in risk management - were analysed by means of a simulation model of the weather insurance market. This was not a model in the usual understanding of the word. The model did not describe actual behaviour; its outcomes were not predictions. Instead, the model was a heuristic device; its mechanisms are metaphors of real world processes. Consequently, the model yielded qualitative insights, not quantitative results. The model only comprised the major features of the market. The core of the model was formed by the behavioural assumptions for the principle agents (i.e., insured, insurer, reinsurer), from which supply of and demand for insurance was derived. Cover, premium *etcetera* follow from assuming market equilibrium. The simplicity of the models allowed us to evaluate many different climate change scenarios, model settings and responses. This approach was chosen to be able to identify the robustness of the outcomes with respect to changes in the assumptions, and thus to yield insight on what might happen to the real insurance market under certain climate change scenarios, given certain responses. The model results were compared to observed reactions of the insurance sector to historical changes in exposure. The special case of small island states was investigated with a simple analytical model.

The economic analysis evaluated both the impacts considered in the case studies and, in a more abstract way, the economic impacts of extreme weather events and risk management. The applicability of economic accounts, and production, consumption and investment patterns directly after a natural disaster and on the longer term were discussed. Most of the analysis was qualitative, but the investigations into issues in the longer term and disaster management were supplemented with simple mathematical models.

Then, the attention turned to the process of policy making. The cases considered posed very different policy problems. These were analysed from the point of view of policy sciences.

Finally, the methodological approach was reconsidered, based on introspection with the question in mind 'given what we know now, how would we have liked the project to be formulated three years ago?'

III MAIN RESULTS

Systems view

Extreme weather events are to be viewed as interactions between natural violence and society. The risk, i.e., the chance of something adverse to happen, depends on both weather hazard and vulnerability. Vulnerability is largely, and to a large extent unintentionally, shaped by human decisions.

Weather-hazard scenarios.

Weather hazards will certainly change with changes in global and regional climates. However, the extent and pattern of the changes is highly uncertain. This uncertainty stems from a poor understanding of the current extremes of weather: time series of historical events are too short, and climate models are not yet sufficiently detailed and robust.

It may be useful, however, to break down the uncertainty into three domains. For events directly related to heat, there is some convergence in present understanding of responses to climate change. Almost all models show regional warming, although some locales may diverge markedly from the regional pattern.

For other hazards, particularly those related to a combination of temperature and precipitation, GCM scenarios can provide a reasonable, divergent but realistic range of results for which analysts could assign probabilities.

The most difficult risks to gauge are complex assemblages of meteorological elements, and ones that are relatively short-lived. Wind storms are typical: to model their current or future distribution requires realistic representation of extreme pressure gradients and frontal systems, over the course of a day or less.

For any given region, changes in weather hazards may involve essentially new hazards, and increases or decreases of frequency, severity and duration of present hazards.

Next to hazard, the other main component of risk is vulnerability. Vulnerability depends in a complex manner on the economic, social and political situations, which are shaped by past extreme weather events and a myriad of other issues. The project focused on the adequacy of current coping mechanisms, and on ways in which they can be enhanced. In all six case studies, it turned out that the current coping mechanisms are adequate, but need to be reinforced to meet the extra demands of climate change.

Clay-shrinkage induced land subsidence is a major issue in the UK, with average losses amounting to £400 million per year. In the UK, property insurance covers subsidence. As a reaction to the losses, insurance premia have been raised. Drought patterns are expected to shift with climate change, but only one climate scenario is combined with a soil map of Europe. Management of further damage presumes the mapping of subsidence-sensitive areas. Options include appropriate building designs, and, for the insurers, restricted cover and capped claims

The risk of **agricultural drought** in Europe is likely to change with climate. From the limited analysis undertaken here, the hazard may alleviate somewhat in northern Europe and worsen in southern Europe. For specific crops, especially winter wheat, the combined effects of a CO_2-fertilization and temperature change, with little changes in precipitation, would lead to increased mean yields, at least in the shorter run. A decreased risk of drought is likely for the UK South Downs, although with a rather greater variability of year to year yield than at present, particularly if earlier drilling dates are adopted. For winter wheat in southern France, climate change would also appear to produce positive impacts (for the crops investigated), with the frequency of droughts diminishing strongly, although implications for water demand and supply are less clear. In the longer run, prospects are more negative, and the competition for (irrigation) water may increase. Options for agricultural adjustment at the farm level can be classified in five groups: land management (e.g., irrigation, mulching), crop variety and land use (e.g., cultivars, crop rotation), planting and harvesting (e.g., timing), fertility and pest management (e.g., fertiliser application) and economic adjustments at the farm level (e.g., investment in equipment, savings). Other developments (e.g., EU agricultural policy) may well dominate farmers strategies.

Three case studies of **riverine floods** were reported: Thames (near London, UK), Seine (Ile the France), and Meuse (Limburg, the Netherlands). Climate change could well increase precipitation and runoff in northern Europe, but the predicted changes in precipitation are, overall, fairly small. In all three cases, however, a small increase in flood depths could increase damage substantially. But, in absolute terms, the additional damage is small. Hence, substantial changes in flood-risk management policies may not be justified by expectations of climate change, although only one GCM scenario was evaluated. In southern Europe average runoff volumes tend to decrease. However, a decrease of annual precipitation might be accompanied by rare but intense rainfall in the summer, increasing the risks of local (flash) flood.

A thousand year history of river floods and flood management in the Dutch Rhine Delta illustrates the linkages between economic development, climate change, political changes and technological developments. It is argued that a comprehensive, dynamic look at hazards and vulnerability is the only fruitful way forward to a full understanding and hence proper management of weather related risks.

The clearest projection of climate change in Europe is for increased temperatures, and these would dramatically increase the frequency and duration of heat waves. However, the effects of heat waves are mixed. The direct effects on health are apparent, but not economically large and are covered, if serious, through medical insurance or health care. Northern Europe appears more vulnerable than southern Europe by lack of current adaptation to hot weather. Significant costs could accrue through increased cooling, particularly as northern Europe passes a threshold for adoption of air conditioning in stores, work places and homes.

Wind storms in Northwest Europe may increase somewhat in intensity, although uncertainty is large. For an extreme storm, a 6% increase in wind speed -- not considered unlikely in 50 years time -- could result in a tripling of damage. Annual average storm damage roughly doubles for this case. At present, wind storms have only temporary effects. Storm risk proved to be much more sensitive to climate change than socio-economic development. A possible response option would be to adapt building codes. The insurance sector may increase premia and, particularly, deductibles.

The research on **tropical cyclones in the Southwest Pacific (Fiji)** included an analysis of the occurrence of tropical cyclones in the region, an analysis of the impacts of three recent tropical cyclones on Fiji. An inhabitant of a rural area in Fiji faces a risk of falling victim to a cyclone that is orders of magnitude larger then the risk to drowning in The Netherlands from a flood. The return period of a major tropical cyclone is about ten years. Prospects for future risk are inconclusive. The current risk is a constraint for various economic sectors and specific disasters consume a significant portion of private and public financial reserves. Tropical cyclones combined with sea-level rise constitute a new risk which warrants policy measures.

Insurance is a major form of risk management for wind storms and subsidence. Hospital admissions resulting from heat stress will be covered by health insurance. Crop insurance is rare. In Fiji, buildings can be insured for tropical cyclone damage, provided building codes are respected. In the UK, commercial insurance for river flood damage is available. In France, a government-subsidised insurance is mandatory. In The Netherlands, flood damage cannot be insured.

The impact of hurricanes and, to a lesser extent, floods and winterstorms on the insurance sector can be dramatic, particularly in the case of underpricing resulting from competition and faulty risk analysis.

The insurance sector has a suite of instruments to respond to changing risks. Measures regarding price and cover can be applied rapidly, often to the disadvantage of the insured. Measures regarding buffer-capacity and risk management require more time and imply structural change, but are to the advantage of both insurer and insured. Empirical evidence from the first half of the nineties suggest that all instruments are applied; particularly price and cover measures are a success (for the insurers). The stylised model of the insurance market developed in the project suggests that short term reactions of market variables depend on the speed with which actors acknowledge changes, but the at the longer term increases in risk are largely borne by the insured, through price increases and cover restrictions.

Although the direct and indirect impact of a natural disaster is by definition negative, and can be substantial and dramatic, the higher order economic impact of such an event is mixed, depending on circumstances. Conventional economic indicators, such as GDP or unemployment rates, usually conceal the real impact. The loss of capital can on the longer term have a positive effect, provided that sufficient reinvestment from designated reserves takes place.

The true economic impact of weather hazards is revealed in the means spent on disaster management. Scarce resources are allocated to things not intrinsically worthwhile, an opportunity cost. This reduces the capacity to generate welfare and growth. Unfortunately, no reliable or complete estimate has been found of the actual expenditure on disaster management. Should the risk imposed by extreme weather change, for instance because of climate change, then the level of adaptation is bound to lag behind the actual change in risk. In addition to the change in opportunity costs (either for the good or for the worse), this induces a transition loss which is invariably for the worse (unless decisions are made haphazardly).

The **policy analysis** study reflected on how scientific information (e.g. presented in the rest of the study) eventually may lead to decisions by policy makers. It stressed the importance of the interaction between the domains of policy development and science in the process of decision making.

The review of the methodological approach suggested that, *in lieu* of scenarios of climate change, vulnerability and adaptation are to be placed in the heart of future analyses of the impact of climate change and extreme weather events.

IV SCIENTIFIC INTEREST AND POLICY RELEVANCE

Scientific interest

Working group III of the International Panel for Climate Change (IPCC) estimated in their second assessment report that the annual economic impact of climate change from a doubling of CO_2 concentrations was of the order of a few per cent of the national income of a developed country. This estimate does not include the costs from extreme events such as windstorms, floods and droughts (heat stress was included, though). The research have pointed out that the latter costs were of less importance, although a strong reservation is necessary as the analysis was far from comprehensive. For The Netherlands, the costs from windstorms and floods (damage and adaptation) added up to roughly 0.1 per cent of the Dutch national income. The Dutch situation may be indicative for the northern part of Europe under climatic and economic conditions similar to The Netherlands. In less developed countries, such as small island states in tropical areas, the relative importance of extreme weather events may well be greater as vulnerability is negatively correlated with economic development.

However, the impact of disasters goes much further than average economic damage. A single event may trigger political processes and force policy decisions on emission abatement and adaptation, otherwise not made. The risk of increasing climate hazards is already put forward in the international debate on greenhouse gas emission control.

A second point to note is that much of the impacts are contingent upon the context, geographically, economically and politically. So far, with the currently expected rate of climate change, the influence of these contextual factors may well be as large as the effect of climate change itself. Therefore, future research should concentrate more on socio-economic factors in the climate risk.

The research of these type of issues calls for a strategic cyclical scaling approach, alternating broad scale analyses and case studies. The present research has been exploratory, focusing on methodologies as empirical data was scarce. The next logical step is a sequence of case studies, particularly with regard to the opportunities for, barriers to, and limitations of adaptation.
Research questions evolving out this explorative study were:

- How to develop databases for systematic analysis of hazards and vulnerability?
- What are the hazards and vulnerabilities of other regions in the world?
- How do these vulnerabilities develop, without climate change?
- What are the mechanisms and the conditions for reduction of vulnerability?

- How does climate risk, impacts and policy interact with vulnerability?

Note that climate modelling is not mentioned. It is strongly felt that, in contrast with the IPCC Common Methodology, the starting point for climate change impact assessment should be the study of existing mechanisms for coping with and adapting to climate change, instead of scenarios of climate change

Policy relevance

The research was relevant in three policy domains: climate change policy making (e.g., negotiations within the UN-FCCC, disaster management, and the insurance industry.

Climate change and greenhouse gas emission policy. In the very first assessment, the overall economic impact seemed to be of minor importance in the European Union from an strictly (macro)economic point of view. Single events may be dramatic, however, and could be used to develop the necessary support for climate change policy, thus acting as triggers for both emission abatement and adaptation. Northern Europe is expected to suffer more from heat stress and river floods than southern Europe. On the other hand, Southern Europe may experience more damage than northern Europe with regard to drought and competition for water, and, perhaps, from summer (flash) floods.

The less developed world is less prepared for changing weather hazards. Unless their physical and socio-economic vulnerability is reduced, disaster impacts will stay on the rise. The EU may promote development programmes that take pro-active account of the weather hazards in the regions concerned, by focusing on development that is relatively robust to a wide variety of possible climate changes. For such intentions to come true it is required to build capacity for risk analysis.

The vulnerability of small island states to climate change reconfirmed in this research is an incentive for them to maintain, or even reinforce their current position in international negotiations, which calls for substantive greenhouse gas emission control in the OECD countries and compensation for suffered damage.

Disaster management. For the time being, it is up to disaster managers to intensify and, possibly, adapt their policies to new climatic conditions, recognising the many uncertainties in climate change and its impacts. The best way forward seems to be to focus on robust policies, that is, policies that work out reasonably well under a wide variation of future weather hazards, rather than on fragile policies, which may work perfectly well under one scenario, but fail under others. There is a scope for policies which promote a pro-active attitude in development programmes, and to increase the support for reduction of greenhouse gas emissions. As such, climate change policy and disaster policy can be mutually supportive.

Insurance. It appears that the insurance industry, as a whole, will not be threatened with collapse by climate change, at least in the next few decades, provided that possible changes in exposures are taken into account, and provided that exposure does not change too rapidly. Individual companies may of course get into trouble. Successful adaptation requires sound technical pricing based on proper risk analysis taking into account climate change and its impacts. However, a residual risk from unexpected climate change cannot be covered. Therefore, strategically, the insurance industry should support greenhouse gas emission reduction policies. At the 1995 Berlin Conference of the Parties, the insurance industry acted accordingly.