# Climate change: From global concern to regional challenge

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**CLIMATE CHANGE: FROM GLOBAL CONCERN TO REGIONAL CHALLENGE**

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> *"Climate change is now a scientifically established fact. The exact impact of greenhouse gas emission is not easy to forecast and there is a lot of uncertainly in the science when it comes to predictive capability. But we now know nough to recognize that there are large risks, potentially catastrophic ones, including the melting of ice-sheets on Greenland and the West Antarctic (which would place many countries under water) and changes in the course of the Gulf Stream that would bring about drastic climatic changes".*
>
> (Human Development Report 2007/2008, p. 3)

> *"Even if we were living in a world where all people had the same standard of living and were impacted by climate change in the same way, we would still have to act. If the world were a single country, with its citizens all enjoying similar income levels and all exposed more or less to the same effects of climate change, the threat of global warming could still lead to substantial damage to human well-being and prosperity by the end of this century. In reality, the world is a heterogeneous place: people have unequal incomes and wealth and climate change will affect regions very differently".*
>
> (Human Development Report 2007/2008, p. 3)

**Abstract**

This paper aims to map out various research and policy challenges inherent in the need to cope with climate change. Therefore, four critical domains are identified which will most likely be seriously affected by climate change. Next, both the global/general and the regional/specific dimensions of these domains are described, with a view to the identification of a proactive research and policy constellation that might be put in effect to effectively address climate issues.

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## 1. Introduction

Climate change has become a serious and world-wide concern. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report issued in 2007 recognizes that warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC Fourth Assessment Report 2007). Scientists are increasingly confident that this is due to the rise in man-made greenhouse gas emissions caused mainly by industrialization and lifestyle.

Observational evidence from all contents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. Higher temperatures are leading to widespread melting of snow and ice, and rising sea levels. Their effects can be felt in a changing global climate, whether as increased rainfall and more frequent storms in some parts of the world, or more intense and longer droughts in others. The impact on fresh water access, food production and health will vary across the globe, but is likely to be destructive and to grow over time.

During the last two decades of the 20th century, the importance of transboundary environmental problems, especially related to water, air and biodiversity, has been increasingly recognized, resulting in the adoption of many international agreements and associated policy plans (e.g., Nijkamp and Castells 2001).[1] Climate change as a result of greenhouse gas emissions is one of those areas that have become a source of both policy concern and scientific inspiration (see, e.g., Lieberman et al. 2007). Dedicated policies to cope with climate changes – at regional, national and international levels – are normally characterized by much uncertainty and substantial costs. Various countries have decided to resort to market-based principles within a system of regulations and legally binding targets. A tradable permit system is one of such examples, where maximum constraints on environmental quality (i.e., fixed reduction rates of $CO_2$ for different main regions of our world) are imposed. A world-wide system of emission rights and sales (or transfers) does, however, cause very complex policy responses that ought to be investigated in the context of multiregional economic-environmental equilibrium modelling (see, amongst many others, Castelnuovo et al. 2005, Copeland and Taylor 2005, and Gerlagh and Van der Zwaan 2006).

[1] Examples of such agreements are the Rio de Janeiro Declaration on Environment and Development (1992); the Convention for the Protection of the Marine Environment of the North-East Atlantic (1999); the UN Convention on the Law of the Non-Navigational Use of International Watercourses (1997); the Convention on Long-Range Transboundary Air Pollution (1979, 1985, 1988, 1994); the Montreal Protocol on Substances that Deplete the Ozone Layer (1987, 1990, 1991 and 1992); the UN Framework Convention on Climate Change (1992, and further); the Convention on Biodiversity (1992); and the International Tropical Timber Agreement (1994).

Global climate change policies prompt of course responses in the production and consumption system and hence in international trade, but are seen to be desirable to combat the externalities of $CO_2$ emissions (see also IPCC 2007). There are evidently winners and losers in this competitive game. The nations of our world have tried to resolve the coordination issues inherent in international climate change policy through the establishment of the UN Framework Convention on Climate Change and its subsequent Kyoto Protocol (KP). This Protocol reflects essentially different national interests based on the principle of common but differentiated responsibilities in a global climate change policy (see, for example, Kuik 2005, Kuik and Mulder 2004, Kuik and Verbruggen 2002, and OECD 1999). The long negotiation procedures until its final (partial) acceptance in 2005 and the more recently experienced new problems in Bali (Indonesia) are clear reflections of the complexity of consensus formation on issues where different interests are at stake.

It is widely acknowledged that indicators of sustainable development are important tools to increase focus on sustainable development and to assist decisions-makers at all levels to adopt sound national sustainable development policies. Indicators of sustainable development have flourished since the time of the Brundtland Commission, in line with the increased recognition of sustainable development as an integral part of policy making. Across the world, a multitude of indicator systems has been developed on international, regional, national and local scales. The Compendium of Sustainable Development Indicator Initiatives, a database maintained by the International Institute for Sustainable Development, contains 669 indicator initiatives as of December 2005.

A rough grouping of these approaches would include:

- Extended national accounts – the UN System of Environmental and Economic Accounts; the World Bank's measure of adjusted net savings; the genuine progress indicator / index of sustainable economics welfare.
- Biophysical accounts – the ecological footprint, the global 'ecological rucksacks'.
- Unweighted indices – the living planet index, the environmental sustainability index.
- Weighted indices – environmental pressure indices by theme.
- Eco-efficiency – resource flows in total and per unit of GDP.
- Indicators sets – as published by the UN Commission for Sustainable Development and many countries.

However, while sustainability indicators, indices and reporting systems have gained growing popularity in both the public and private sectors, their effectiveness in influencing actual policy and practices often remained limited.

Over the years, a number of methodologies have been developed as a vehicle to integrate ecological understanding and economic considerations concerning the environment. The target was to find methods to attach an operational value to the environment and its resources and to manage then in a sustainable matter. Based on standard economic theories, ecological economists have often deployed the distinction between a use value and a non-use value of natural resources. The first case occurs when a change in the resource affects market behaviours. In this case, the cost to society is very straightforward to calculate, since it is revealed directly in in market prices. It does not matter whether the change in the resource is real or it is only a common belief, rather it is important that it causes direct impact on the market, mirrored by a shift in the demand or in the supply. On the other hand, a resource is said to have a non-use value when a change in it is not reflected in market behaviour. This usually occurs when the resource is not marketable, there is no property for it, or its utility is not well acknowledged by the population yet. The latter aspect is relevant when we consider the environment or climate change. In fact, a current non-use value may turn into a use value in the future, when more knowledge is available on how ecosystems function. However, in all these cases the price is not set by the classical meeting place between supply and demand (i.e. the market), and it can therefore be more complex to establish.

## 2. Global Changes, Regional Impacts

Climate change will most likely act as a 'pervasive technology '. It will gradually enter the lives of all people, although different groups – depending on their socio-economic position and geographic location – may be affected differently. In the UNDP Human Development Report 2007/2008, five key transmission mechanisms are distinguished through which climate change may impact on human development:

- Agricultural production and food security (through changes in rainfall, temperature and water availability).
- Water stress and water insecurity (through changes in run-off patterns and glacial melt).
- Rising sea levels and exposure to climate disasters (through accelerated ice sheet disintegration).
- Ecosystems and biodiversity (through world-wide quantitative and qualitative changes in ecological systems).
- Human health (through, e.g., heat waves and extreme summer and winter conditions).

It is clear that such mechanisms may exhibit significant differences in different regions of our world. We will focus on the Netherlands in the present paper. To map out the various possible impacts of climate change, we present here an exploratory approach by using a two stage stimulus-response framework. Given the specific nature of land use and the environment in the Netherlands, we distinguish first the most likely climatological factors at work, followed by a description of the most likely impacts on spatial-economic activities in this country. We believe however, that our analytical framework has also a great relevance for many other countries. Our analysis will be presented at two levels, viz. global and national-regional.

Relevant effects of climate change in the Netherlands are predicted to be sea level rise, high water levels in rivers, low water levels in rivers, extreme rainfall, draughts, high temperatures and possibly changing wind directions and wind-force. In this study we have decided to link these climate change effects to the field of spatial economics through the perspective of land use. Land use is an important concept in spatial economics that provides a promising point of entry, because it is here that economic activities and physical conditions probably can most easily be connected.

Table 1 shows which key transmissions will most likely be affected by the distinguished climate change effects (four critical dimensions are distinguished). Although most information in the table is clear, some issues deserve further attention. Agriculture may be affected by high and low water levels and rainfall, because both too much and too little water supply may negatively influence production of (certain) crops. Water safety is defined fairly broadly and includes issues such as draughts, flooding incidences and fresh water storage; both high and low water levels and rainfall estimates are therefore relevant. The four dimensions in Table 1 will now be addressed in Sections 3-6 successively, from both a general and a Dutch perspective

Table 1: Possible effect of climate change on key transmissions

| | Sea water level | River water levels | | Rainfall | | Temperature |
|---|---|---|---|---|---|---|
| Land-use | High | High | Low | High | Low | High |
| Agriculture | X | X | X | X | X | |
| Water safety | X | X | X | X | X | |
| Ecosystems | X | X | | | X | X |
| Human health | X | X | | X | | X |

## 3. Agricultural Production

### *3.1 General*

The growing world population and the growing welfare in countries such as China and India result in an increasing demand for agricultural products, both food and fibre. The productivity of European agriculture is generally high, particularly in Western Europe. Average cereal yields in

EU countries are more than 60 per cent higher than the world average (Olesen et al. 2008). However, the hydrological features in Europe are very diverse, and there is also a large diversity in water use, pressure and management approaches. About 30 per cent of the fresh water extracted in Europe is used for agricultural purposes, primarily for irrigation. However, the proportion is only 4 per cent in the Northern part of the EU, and as high as 44 per cent in Southern EU countries (Flörke and Alcamo 2005).

The problems caused by climate change will predominate in southern areas. The potential increase in water shortage and extreme weather conditions may cause lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops (Olesen et al. 2008). This means that some of the low input farming systems, currently located in marginal areas, may be most severely affected by climate change (Reilly and Schimmelpfennig 1999).

In northern areas, on the other hand, climate change may produce positive effects on agriculture through the introduction of new crop species and varieties, higher crop production and expansion of suitable areas for crop cultivation. Adverse effects may include an increase in the need for plant protection, the risk of nutrient leaching and the depletion of soil organic matter. However, intensive farming systems in Western Europe generally have a low sensitivity to climate change because changes in temperature or rainfall have modest impact (Chloupek et al. 2004). Furthermore, these farmers generally have resources to adapt and compensate by changing management practices (Olesen and Bindi 2002).

Besides the effects of climate change on the yield and quality of harvested products, damage to crops and building structures are of importance to agriculture. Extreme weather conditions, such as spells of high temperature, heavy storms or droughts, can severely disrupt crop production. While individual extreme events will not generally have lasting effects on the agricultural system it is clear that, if the frequency of such events increases, then agriculture needs to respond, either in terms of adaptation or abandonment (Olesen et al. 2008).

### *3.2 The Netherlands*

In the Netherlands, 9.4 per cent of the total national added value comes from the agro-business complex, half of which is from businesses that deal with primary products from the Netherlands. Furthermore, the Netherlands is the second biggest exporter of agricultural products and food (in $/year) (minLNV 2008).

Most effects of climate change in the Netherlands on agriculture will be caused by extreme river water levels and extreme weather conditions like heavy showers and drought resulting in more diverse production levels. For the fisheries sector the main impacts from future climate conditions are related to the increasing water temperature of the North Sea, estuaries, rivers and lakes, the frequency of storms, and changing levels of salt and freshwater due to extreme weather and river conditions (MNP 2005a).

In the low lying areas in the western and northern parts of the Netherlands and in river valleys, peak river discharges will result in more frequent events of flooding on farmland, and in addition, extremely low river discharges can result in salinisation of ground and surface water in the coastal zones. These impacts are reinforced by sea level rise (de Groot et al. 2006).

In contrast to the lower parts of the Netherlands the higher parts can suffer from water shortage. Today, dry periods already affect the sensitive sandy areas. In the southern tip of the Netherlands erosion is expected to increase on loessial soils due to heavy showers (Van Ierland et al. 2001; MNP 2005a).

At the same time, rising temperatures could result in higher crop productivity. However, Ewert et al. (2005) who looked at future changes in the productivity of food crops in Europe, found that changes in crop productivity, over the period 1961 – 1990, were chiefly related to technology development and the effects of climate change were relatively small. Also, for the future they expect an increase in crop productivities, mainly thanks to technological changes. Especially in Western and Northern Europe, including the Netherlands, the effect of climate change is thought to be relatively small (van Drunen 2006).

Besides the direct effects, indirect effects such as saline intrusion and changes in the abundance and pressure of pests and diseases can have a dramatic effect on production levels locally. It is however unclear how these will develop (de Groot et al. 2006).

## 4. Water Stress and Rising Sea Levels

### *4.1 General*

Drought and floods claim more lives than all other natural catastrophes. An analysis of the hundred most deadly and the hundred most expensive natural catastrophes since 1950 reveals that droughts caused more than half of all fatalities while, around a quarter of the fatalities were caused by flooding (Kron 2006). However, as droughts mainly affect developing countries, floods have serious impacts all over the world. In 2007, the OECD published a report about the risk of coastal flooding of cities worldwide. The analysis focused on the exposure of population and assets to a 1 in 100 year surge-induced flood occurrence (assuming no defences are in place), rather than the ‘risk’ of coastal flooding. The ten cities with the highest population exposure today are almost equally split between developed and developing countries. When assets are taken into consideration, more developed countries enter the top 10, as the wealth of the cities becomes important. The top 10 cities in this ranking are Miami, Greater New York, New Orleans, Osaka-Kobe, Tokyo, Amsterdam, Rotterdam, Nagoya, Tampa-St Petersburg and Virginia Beach. These cities represent 60% of the total exposure, but are from only three (wealthy) countries: USA, Japan and the Netherlands. However, in the future it is expected that both population and assets will increase significantly in developing countries, increasing the risk there as well.

### *4.2 The Netherlands*

In the year 1000 AD the Dutch started to drain the coastal wetlands of what is now the Netherlands. However, after draining, the land subsided due to geo-physical and chemical processes, hence to protect it dykes were built. When there was no flooding, subsidence increased as deposition of new silt and clay ceased, and the growth of new peat was inhibited. This meant that the dykes had to be heightened again, and so on; today, the difference between the top of the dikes and the land surface in some places now exceeds 10 metres. This, together with a gradually subsiding geological base and predictions of rising sea level due to climate changes could cause problematic situations in the future (Wesselink 2007).

The Dutch coastline consists mostly of sandy beaches and dunes, with the exception of the old but highest (about +12m NAP) Hondsbossche and Pettener sea dykes and the Delta Works, the estuarine peninsulas of South-Holland and Zeeland which are connected by storm surge barriers. Furthermore, a large system of dykes along the river Rhine, Meuse, Waal and IJssel are part of the Dutch protection structures. About half of the Netherlands is situated below mean sea level, and about 60% of the Dutch GDP is earned here.

### 4.3 *Freshwater shortage*

When the sea level rises, it can result in a stronger infiltration of salt water into the river mouths, as well as into the groundwater in the west of the Netherlands. This salination process, as well as the predicted water shortages during summertime, can adversely affect the availability of fresh water in certain areas. Especially for water-intensive agricultural activities such as horticulture, as well as for other water-intensive economic activities this could lead to significant damage. When less fresh water is available it will possibly raise the water price for businesses as well as for households. However, not much research is available on this topic.

### *4.4 Flood risk*

It is difficult, if not impossible, to compare the safety standards (if in place) of different countries. This is because of the various methods, models and underlying assumptions in monitoring hydraulic boundary conditions. The 10,000 year safety standard in the Netherlands was matched with the most unfavourable water level (+5m NAP at Hoek van Holland) that could have happened during the flood disaster of 1953 if all possible negative conditions had interacted. Most safety standards in, for example, the other North Sea countries are based on (deterministic) design water levels for a certain return period. In the Netherlands, each protective structure has a different safety level, expressed in a maximum acceptable flood return period. These safety levels have legal status and range from once every 1,250 years to once every 10,000 years. Safety levels are highest in the western part of the Netherlands and become gradually lower when moving from west to east. Safety levels are based on the probability of flooding (overtopping of dykes) and the consequences caused by flooding in terms of potential casualties, material damage to buildings and economic losses in flood-prone areas (Brouwer and van Ek 2004).

In general, it is difficult to assess the risk of flood and to design facilities such that the risk is appropriately small. Among the reasons, apart from scarcity of data and unknown probability distributions (surprisingly, the exact strength or capacity of dykes is not exactly known), is the lack of objective measures of acceptable risk.

To estimate the risk of flooding from an economic point of view, both the probability of a flood as well as the economic damage caused by a flood should be taken into account. Future risk can be defined as the probability of a flood under changed scenarios multiplied by the consequence under changed scenarios (TNO 2008). Although this definition is often used, it does not take into account two important aspects. First of all, the damage depends on the specific location of the dyke failure and secondly, the total risk is not only the risk in a single year, but also the probability of dyke failure in the coming years plays a role. Not the heightened probability, but the expected yearly loss by flooding is the key variable in an optimal safety strategy in the case of economic growth (Eijgenraam 2006). Furthermore, the risk level can be based either on individual risk (the probability of being killed by a flood) and group risk (the probability of a group of people being killed by a flood) (Vrijling et al. 1998). Flooding risks are usually modelled with the help of river stream models and flooding scenarios (e.g. van Manen and Brinkhuis 2005).

## 5. Ecosystems and Biodiversity

### *5.1 General*

Climate and weather directly control the distribution, productivity and many other aspects of species, ecosystems and landscapes. However, on smaller temporal and spatial scales, the dominant role of climate is limited. In this respect local differences in soil, terrain and hydrological properties determine the occurrence of species and ecosystems (Leemans and Eickhout 2004). In addition, over the last millennia humans have managed species, ecosystems and landscapes to obtain specific goods and services.

The direct impacts of climate change on ecosystems are chiefly due to rising temperatures that lead to changes in life-cycle timing (date of flowering, ripening of fruits, leaf unfolding and species migration) which impact entire ecosystems (de Groot, et al. 2006). Few ecosystems can adjust to a rise of 3°C or more. More than 20 per cent of the ecosystems worldwide would then completely change and more than 20 per cent of all marsh areas will be lost (MNP 2005a). Indirect impacts include changes in precipitation and drought frequency, changing water levels that may result in an increased risk of flooding, and extreme weather conditions including frost, fire and storms.

According to Leemans and Eickhout (2004), who used a relatively simple but widely-used ecosystem model (IMAGE) embedded in a comprehensive integrated assessment model, even minor climate changes will have substantial consequences on temperature-limited ecosystems, such as tundra's. In addition, while all other ecosystems will be influenced, there are large regional differences depending on the original species, ecosystem and landscape, their sensitivity and exposure to regional changes in temperature and precipitation patterns.

When the pace of temperature change becomes too high to allow certain plants and animals to adapt or migrate, widely-occurring species of plants and animals are most likely to extend their range, and there is a greater chance that more sensitive species will become extinct. This could result in an invasion of exotic species. The so-called 'invasive species' may have substantial social, and ecological consequences. In the U.S. some invasive species have caused major economic losses in agriculture, forestry, and several other segments of the economy, apart from harming the environment. One study reported approximately $97 billion in damages from 79 exotic species during the period from 1906 to 1991 (OTA, 1993 in Pimentel et al. 2005). A difficult question, from a management point of view, is how to respond to this. More and better quantitative estimates of invasive-species costs would substantially strengthen decision making, making it possible to evaluate the outcomes of alternative policy and management actions (Chornesky et al. 2005).

### *5.2 The Netherlands*

The projected climate changes in the Netherlands will probably result in a decreasing diversity of species. In particular plants and animals from southern regions will settle in the Netherlands. Amphibians and reptiles seem to be less mobile and their changes appear to be influenced more by the restoration of the biotope and nature conservation than by global warming.

At present, particularly the effects of the rise in temperature can already be observed (MNP 2005a). For example, it has been observed that plants and animals are migrating northwards and that spring is beginning earlier. Furthermore, relationships in the food chain are becoming disrupted, which is especially a problem for migratory animals (mostly birds). In the North Sea and Wadden Sea, plankton, which is the basis of all food chains in the sea, is changing; this leads to changes higher up in the food chain, and the higher water temperatures also affect certain fish species.

Wet natural environments such as wet hay meadows and floodplain woodlands can benefit from the increasing rainfall in the spring and winter. The extent of this benefit will depend on how water management responds to these changing weather conditions: if the water is retained, the natural environment is given an extra chance to recover. However, the summers will become drier and the water deficits greater. As a result, the water level will drop even further in summer or, in areas with a controlled water level, more water will have to be let in.

The Wadden Sea, covering parts of the Netherlands, Germany and Denmark is one of the largest wetlands in Europe; this is an area which is important for many different species. It is a valuable nursery area for commercial fish such as herring and plaice, and harbour seals can be found along the coast (Safecoast 2008). For the Wadden Sea, the rate at which the sea level rises is more important than the absolute rise in sea level. If this rate increases above a critical value, sedimentation might no longer keep pace, and sandbanks and salt marshes will become submerged (MNP, 2005).

In lower-lying parts of the Netherlands and areas adjacent to the rivers Rhine and Meuse, flooding will increase. An increase in the duration of floods can cause serious problems for plants and animals in wetlands including the disappearance of trees that will likely be replaced by herbal vegetation (van Ierland et al. 2001). The expected more frequent occurrence of extreme weather conditions can be disadvantageous for less dynamic natural species, especially if their habitats are strongly fragmented.

## 6. Human Health

### *6.1 General*

Since many years, built up areas are regarded as having a less healthy environment than rural areas. Emissions from industrial activity and traffic and a lack of urban green are the main factors. This difference will increase due to the (expected) rising temperatures.

Heat waves are sporadic but recurrent, and are considered a mere annoyance, rather than a threat; however, the extra mortality because of the extremely warm summer in 2003 is estimated at 35,000 persons in Europe (AR4 2007). In the Netherlands, during the warm month of July in 2006, the mortality rate was 1000 persons higher compared to an average July. The effect of buildings is regarded as one of the main reasons for the urban heat island effect. Building masses increase the thermal capacity, which has a direct bearing on city temperatures. They reduce wind speed and radiate heat through the building fabric and air-conditioning equipment also tends to generate heat. The heat absorbed during the day by the buildings, roads and other constructions in an urban area is released after sunset, creating high temperature differences between urban and rural areas (Rajagopalan et al. 2008). In addition, millions of urban area residents are exposed to elevated levels of urban air pollutants that have been linked to adverse health effects and which can have synergistic effects when combined with heat (Semenza 2008).

*6.2 The Netherlands*

The most important aspects of climate change affecting Dutch cities will be the increasing number of warm days, the increasing number of days with extreme precipitation, and the rise in sea level.

In addition to the negative health effects of the urban heat island effect mentioned above, heat also causes other problems. During heat waves the demand for electricity increases in order to cool machines and buildings. However, for power stations it is more difficult to generate electricity because they too are dependent on the temperature of the cooling water. When this temperature increases too much, the capacity of the power stations decreases and sometimes they even have to stop their activities to protect aquatic ecosystems (van Drunen et al. 2007). Therefore, it is very important to improve the environmental quality in cities and make them heat-resistant in a sustainable way.

Apart from the increasing number of warm days, Dutch cities will also be exposed to more frequent water nuisance due to the increasing number of heavy showers, both in winter and in summertime. Because most of the surface is hardened in the city, the rainwater cannot filter into the ground but has to be discharged out of the city. Furthermore, heavy rainfall can cause problems for traffic and logistic activities in cities (Döpp and Albers 2008), On the other hand, during periods of drought the groundwater level is likely to drop and this can cause damage to buildings in the lower part of the Netherlands which often have wooden foundations. Furthermore, it can damage urban green areas which are very important for their positive effect on the urban climate (van Drunen et al. 2007).

The third challenge could be the rising (sea) water level. Most cities in the Netherlands are located in the lower part of the Netherlands. While Amsterdam is just below sea level, parts of Rotterdam are as much as 4 metres below. However, the dunes and dykes will probably be strong enough to protect the area for a long time (hundreds of years). Therefore the general opinion is that relocating investments from the lower parts to higher areas outside the Randstad is not (yet) necessary (MNP 2005b).

## 7. Adaptation to Climate Change, What Do Regions Need to Know?

Over time, both natural and human systems have adapted to spatial differences in climate. There also are examples of adaptation to temporal variations notably, deviations from annual average conditions. Many social and economic systems-including agriculture, forestry, settlements, human health, and water resource management-have evolved to accommodate some deviations from "normal" conditions, but rarely the extremes.

Adaptations come in a huge variety of forms. The extent to which society can rely on autonomous, private, or market adaptation to reduce the costs of climate change impacts to an acceptable or non-dangerous level is an issue of great interest. Unfortunately, there is little evidence to date that efficient and effective adaptations to climate change risks will be undertaken autonomously (IPCC, 2001). In this section, we discuss several issues that are important for regional policy and that need to be taken into account when thinking about adaptation measures to climate change.

### *7.1 Agricultural production*

Climate change could have serious impacts for the agricultural sector. New diseases could affect crops and animals, some areas could become too wet to be managed in a proper fashion, extreme weather conditions could affect production levels and salination could downgrade productive areas. However, climate change could also result in opportunities for new crops and innovations in aquaculture.

Changes in agricultural land-use and productivity will most likely occur. But, what are the implications for agricultural land use and productivity of salination, dry periods, the need for water buffers, changes in water management, shifts in ground water, plant and animal diseases, etc.? How will these developments affect the suitability of agricultural areas for different kinds of production, e.g. aquatic agriculture? And how could changes in farm management, such as crop rotation schemes, benefit farmers?

The demand for freshwater in the agricultural sector is quite significant. Thus far, freshwater is available for free to the agricultural sector in many countries, for example in the Netherlands. But when the supply of fresh water leads to high costs the guaranteed supply of freshwater may imply high costs as well. Also the transport of freshwater to particular places may imply high costs. It is fruitful to analyse this in terms of a market for freshwater. This calls for the development of dedicated models with spatially differentiated prices for water, taking into account the costs of production.

All in all, farmers will have to cope with variability. Because of more extreme weather conditions, production levels and the related income can differ very much from one year to the next. How can insurance or governmental compensation tools be used in an efficient way to allow farmers to deal with this?

*7.2 Water stress and rising sea levels*

Water is a very important issue when discussing the issues of climate change in  the world as well as in the Netherlands. The rising water levels in the sea and rivers demand major protection and safety measures. There is quite a significant body of literature about this subject, although not so much is written about the potential positive effects of climate change on water management.

An interesting question is how business sectors will respond to flood risks. The risk that an actual disaster - or the high probability that a disaster will take place - may have an adverse effect on the reputation of a country like the Netherlands. How could the costs of this bad reputation be estimated?

Furthermore, more insight is needed in the role of the private sector in the reduction of damage costs due to flood risk. It is clear that, given the physical circumstances in the Netherlands, the public sector has core responsibilities in reducing the risk of flooding. This raises the issue to what extent the private sector can contribute in this respect, for example by reducing the damage costs in the case of calamities, and more in particular how incentive structures may be designed to arrive at an appropriate balance between public and private sector efforts in adaptation?

*7.3 Ecosystems and biodiversity*

As in the rest of the world, also in the Netherlands in particular will the vulnerable nature areas suffer most from extreme weather conditions and rising temperatures. This could lead to a loss of biodiversity. However, climate change will also increase the opportunities for wet nature systems and for more multifunctional land-use solutions.

Ecosystems can provide certain services, such as water storage, (wet) nature areas that prevent a lowering of the soil and the emission of greenhouse gasses from peat lands or preserving the landscape. What are the benefits of ecosystem services?

Another important issue is how to deal with nature policies that focus on protecting special species? What investment levels are acceptable for the preservation of specific species considering their national and international occurrence? When are those protection strategies efficient? Furthermore, what are the implications of climate change on the economic valuation of biodiversity? What is the potential damage of invasive species and what policies are called for to address them?

*7.4 Human health*

In urban areas, especially the increasing number of (very) warm days could have a negative effect on the quality of life of urban residents. Furthermore, extreme levels of precipitation could disrupt transport and logistic processes. However, the decreasing number of cold days could result in lower energy consumption.

It will be necessary to understand the regional implications of climate change (especially the frequency of hot days) on health issues and labour productivity to be able to develop effective measures to cope with this. In addition, the costs and benefits of more greenery in urban areas will be very important to understand. They will be very useful in order to deal with the urban heat island effect, as well as with extreme precipitation taking into account the required additional amenities for residents and visitors.

## 8. Outlook

Greenhouse gas emissions and the resulting global warming followed by climate change have prompted a series of policy and research issues, at both international and national/regional scales. The presented paper has tried to map out critical domains which might be seriously affected by climate change, even though probabilities of occurrence of various events are uncertain or rather low (the 'black swan' phenomenon, see Taleb 2007). There is no doubt a need for planned adaptation to these future challenges.

Clearly, this calls for a global awareness and willingness to change, but also for concrete actions in relation to land-use, regional development, urban policy and water management. Research is needed to analyse adaptability and resilience of regional and urban systems (e.g. through focused scenario experiments and vulnerability analysis), based on solid monitoring systems and policy-relevant indicators, e.g. on critical turning points. The link between knowledge acquisition and policy implementation should be as close as possible by developing scoping mechanisms for anticipating and implementing change. A smart mix of opportunity-seeking and threat-coping policy measures seem to be a wise response of regional authorities to effectively address climate change.

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