Knowledge for Climate

Spatial economic research on climate change and adaptation

Literature review for ‘Knowledge for Climate’

KfC report number KfC 002/09

Spatial economic research on climate change and adaptation

Literature review for 'Knowledge for Climate'

Authors
Eveline van Leeuwen[1]
Mark Koetse[1]
Eric Koomen[1]
Piet Rietveld[1]

vrije Universiteit amsterdam

1) VU University Amsterdam

KfC report number KfC 002/09
ISBN 978-94-90070-02-1

This project (VBR 07 Social scientific literature review on climate adaption) was carried out in the framework of the Dutch National Research Programme Knowledge for Climate. This research programme is co-financed by the Ministry of Housing, Spatial Planning and the Environment (VROM).

Contents

1. Introduction

An exact prediction of future climate changes is impossible. Firstly, because of the uncertainty related to the main causes of climate change. Secondly, because of the even larger uncertainty in feedback processes, both back - and forward-coupling. A third reason is that not all natural systems respond at the same pace of change. Finally, our knowledge about climate systems and the developments through time is very limited, making it difficult to do any predictions (TNO, 2008).

Although there are many uncertainties concerning the causes and degree of climate change in the world and in the Netherlands, some developments are quite certain. By now, most scientists are convinced that human activities are changing the climate (IPCC, 2007). According to the climate scenarios of the KNMI, the Dutch meteorological institute, for the Netherlands this will result in milder winters and warmer summers (KNMI, 2006). Furthermore, it will rain more often in wintertime with more heavy showers (higher extremes). Also during summertime more heavy showers will occur but the number of days with rain will decrease. This will result in longer periods of drought in the summer. The changes in wind intensity and direction are not clear as yet. Furthermore it is expected that the sea level will continue to rise and that the river discharges will be more extreme (extremely high as well as extremely low). These diverse developments call for a diverse range of adaptation measures. In the present report we will discuss the adaptation theme from a spatial economic perspective. Economics is relevant since adaptation implies the use of scarce resources that could be used in alternative ways. Decisions on the intensity of adaptation policies should preferably be based on knowledge about the costs of damage due to climate change. The spatial dimension deserves special attention in this context since climate change has implications on land use, and the same holds true for many adaptation measures.

1.1 Spatial Economic research

Spatial economics is concerned with an explicit consideration of spatial elements in general (theoretical) economics. It studies the spatial dispersion and spatial coherence of activities from an economic point of view. The focus is on the interwoven pattern of spatial phenomena with in general a notion of the relative openness of regions (Paelinck and Nijkamp, 1975). Important themes in spatial economics concern the contribution of various factors to regional economic performance and land use, relevant factors being agglomeration forces, transport costs, human capital and physical conditions. Also spatial interrelationships and spill-overs are studied extensively in spatial economics. A large battery of models and techniques are available for these studies. In the context of the present survey we will focus on land use models. Spatial economics is a natural domain for applications of welfare economic principles, leading to the use of social cost-benefit analysis. The combination of a spatial and an economic focus makes the research field very useful for addressing climate change issues as those that are often characterised by strong spatial and economic components.

Spatial economics today is a dynamic field of research. A major theme that received broad attention during the last decade concerns the study of agglomeration forces that govern metropolitan development. A main contributor to this field has been Paul Krugman, the 2008 Nobel prize winner. Other important themes concern the impact of human resources on economic development, the study of regional disparities and the influence of forces leading to convergence and divergence. The field has an orientation towards both theoretical and empirical work, a link between the two being provided by concepts of general equilibrium modelling. Part of the present day literature is oriented towards policy analytical themes addressing issues of first best or second best policy interventions. Notions derived from social cost-benefit analysis usually function as the basis of these analyses.

When one confronts the theme of climate change with that of spatial economics, it is striking that most of the economic approaches are rather silent on the physical dimensions of the spatial economy. Instead, one can observe a strong interest in institutional, cultural and human capital aspects. Of course, in the neighbouring field of environmental economics the theme of environmental degradation and depletion of natural resources receives ample attention, and also climate change is widely studied here, but the dominant orientation is on mitigation themes. Adaptation receives much less attention here.

1.2 Aim of the study

The aim of this study is to make an inventory of the contributions to the scientific literature that addresses adaptation to climate change from a spatial economic perspective and to formulate relevant (future) research themes. Therefore, a literature review was conducted that includes articles from the core scientific literature[1] and reports from institutes and agencies that act as an interface between policy and

1 As selected by the Sciencedirect platform and Google scholar.

science[2] and thus support national and international policy makers. By using search entries such as ‘climate change adaptation’ combined with terms such as agriculture, nature and tourism, many relevant contributions were found. A striking result is that top journals in the field of spatial economics paid little or no attention to the theme of climate change as far as adaptation is concerned. Therefore we also considered a wide range of journals, where spatial economic aspects play a role, but where also other disciplinary perspectives are used. Thus, we often selected publications with spatial economic relevance from a broader literature with a multidisciplinary orientation. Furthermore, using the snowball approach, additional relevant articles and reports were found.

1.3 Sub-themes

Because spatial economics is a broad research field it was decided to focus on the effect of climate change on spatial (economic) activities and land-use activities. 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 via 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 land-uses will most likely be affected by the distinguished climate change effects. 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. Although road, rail and air transport are mainly affected by high water levels and strong rainfall, the inland navigation sector is mainly affected by low water levels. Finally, 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.

Table 1: Possible effect of climate change on spatial (economic) activities

	Sea water level	**River water levels**		**Rainfall**		**Temperature**	**Wind**
Land-use	High	High	low	high	low	high	Strong
Agriculture	X	X	X	X	X		
Nature	X	X			X	X	
Recreation						X	
Urbanisation	X	X		X		X	
Transport	X	X	X	X			X
Water safety	X	X	X	X	X		
Other*	X	X	X			X	X

*Business activities and energy production

The remainder of this report is organised as follows. Chapter 2 describes the possible effects of climate change on these land-use activities, both in general and from a Dutch perspective. Furthermore, for each land-use adaptation strategies are described together with knowledge gaps. It was decided to add ‘water safety’ as one of the land-use functions in order to discuss important societal issues related to issues such as flood protection and flood risk. Chapter 3 deals with spatial economic analysis and methods that are useful in addressing climate adaptation measures. We focus on scenarios, cost-benefit models and land-use models. Chapter 4 summarises the most important research themes that arise from the literature review. Finally, Chapter 5 gives some concluding remarks. One of our findings is that in the literature there is a rather unbalanced treatment of the various themes covered in Table 1.

2. Spatial Economic Themes

Society will be affected by climate change in many different ways, both from an economic and a spatial perspective. However, large uncertainties and large variations in possible effects make it difficult to obtain

2 Such as the IPCC, OECD, Dutch meteorological institute KNMI, Netherlands Environmental Assessment Agency, TNO, etc.

a clear view on possible developments and hamper a sustainable and efficient response. In this section, we therefore look separately at various spatial and economic activities. We distinguish between agriculture, nature, tourism, urban and transport activities. While most of these activities contribute to climate change as well, we will mainly focus on the effect of climate change on them, as well as on possible adaptation strategies. These adaptation strategies should of course be sustainable and not reinforce climate change. Therefore, it is expected that part of the adaptation strategies may also add to climate change reduction.

2.1 Agriculture

Europe

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 (Olsen 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 be 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 (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, if the frequency of such events increases, then agriculture needs to respond, either in terms of adaptation or abandonment (Olesen et al., 2008).

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, 2005).

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, 2005).

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).

Adaptation

Adapting to changing conditions is to a large extent normal agricultural practice. Dutch farmers have been highly successful in doing so given that they have adequate technical training and financial resources. One way of adapting to climate change is to develop crops that can cope with environmental stresses like saline conditions, drought, flooding and high temperatures. Other opportunities arise when new markets can be served e.g. the energy market (de Groot et al., 2006).

In the lower parts of the Netherlands, especially the peaty grassland areas (Kwakernaak and Rienks, 2005), soils may become too wet in spring and autumn for soil management operations and harvesting with the equipment and machinery currently used. Therefore, an adjustment of crop rotation schemes and planting and harvesting dates could minimise production losses. When certain areas face drought periods too often, advanced irrigation management practices might be a solution, depending on the market price of the product.

Fish production by means of aquaculture in seawater basins on former grassland may increase the economic value of otherwise submerged grassland. Aquaculture in basins on land already takes place in the Netherlands for sole and turbot. However, the efficiency of the adaptation options described often critically depends on market developments and prices.

Finally, also insurance is an important anticipatory adaptation strategy (Kok et al., 2001). Damage due to storms and floods are expected to be the largest loss-making situations. Due to the unknown effects of climate change on weather extremes it is difficult to adjust insurance contributions to the increased risks. Currently, farmers can only insure damage from rain and hail storms, not from snow storms or drought (Werners et al., 2004).

Knowledge gaps

On the basis of this review we observe several knowledge gaps. Little is known about how climate change affects agricultural productivity due to new plant and animal diseases, and how it provides opportunities for producing new crops, for instance in the area of aquatic agriculture. Little is also known about how future changes in farm management, such as crop rotation schemes, could benefit farmers in different regions in the Netherlands. Finally, given the increase in weather variability and extreme circumstances, it is important to know how to deal with local disasters and insurance or compensation payments by the government. In Chapter 4 we will formulate a series of strategic research questions addressing these knowledge gaps.

2.2 Nature

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, 2005). 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. 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).

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, 2005). 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.

Adaptation

Creating more space for water, besides increasing the water storage capacity, can offer room for plant and animal species. Appropriate water management can allow adequate storage of water from heavy rains and can help to counteract drought, both likely consequences of climate change. However, it is quite possible that existing natural habitats are likely to disappear when faced with increasing incidence and/or magnitude of flooding (de Groot et al., 2006).

Furthermore, it is not only the level of climate change that affects the ecosystems but also the vulnerability of the ecosystems themselves and their capacity to adapt. When, for example, nature areas are difficult to access by certain kinds of animals or plants, the adaptive capacity will be weaker. In this context, the National Ecological Network (NEN) is of great importance. However, one of NEN’s main objectives is to protect certain (uncommon) species. Focus in the future should be more on the development of robust and resilient nature areas that can ‘cope with’ climate change and maintain a certain level of biodiversity at the same time (van Leeuwen, 2007). This means that developing a well connected network of large and robust nature areas with smaller or more sensitive ones will be of the utmost importance in the Netherlands.

Knowledge gaps

Vulnerable natural areas will suffer most from extreme weather conditions and rising temperatures. This could lead to a loss of biodiversity but may also increase the opportunities for wet nature systems and for more multifunctional land-use solutions. In this light, little is know about the benefits of ecosystem services, such as (wet) nature areas that prevent a lowering of the soil and the emission of greenhouse gasses from peat lands, and about the possibilities to combine activities such as water storage, nature, agriculture and residential activities. It is also largely unclear how to deal with nature policies that focus on protecting special species when changes in climate are foreseen. A relevant question here is what investment levels are acceptable for the preservation of specific species, considering their national and international occurrence. Strategic research questions addressing these knowledge gaps will be formulated in Chapter 4.

2.3 Tourism

General

Weather can ruin a holiday, while climate can devastate a holiday destination (Becken and Hay, 2007). With its close connections to the environment and climate itself, tourism is considered to be a highly climate-sensitive economic sector similar to agriculture, insurance, energy, and transportation.

First of all, climate is a principal resource for tourism, as it co-determines the suitability of locations for a wide range of tourist activities. Thus, changes in the length and quality of climate-dependent tourism seasons (e.g., sun-and-sea or winter sports holidays) could have considerable implications for competitive relationships between destinations and therefore the profitability of tourism enterprises (Simpson et al., 2008). The majority of tourists spend their holidays lazing in the sun; a sun that should be pleasant but not too hot. The Mediterranean particularly benefits from this, being close to the main holiday-makers of Europe's wealthy, but cool and rainy Northwest (Berrittella et al., 2006). Lise and Tol (2002) found that an average temperature of about 21◦C (over day and night during the warmest month) is the ideal for the majority of international tourists. This preference is largely independent of the tourist’s origin. The optimal temperature corresponds to the present temperatures found in northern Spain, southern France, northern Italy, the former Yugoslavia and Uganda. However, in the future, the currently popular holiday destinations may become too hot, and destinations that are currently too cool would see a surge in their popularity. Furthermore, in the Mediterranean areas, not only will temperatures rise but also the competition between the tourism sector and other sectors since water will become more important, making certain types of activities, such as golf, less attractive. Therefore, climate change could alter the destination choice of tourists, as tourists are particularly footloose (Berrittella et al., 2006).

Climate change not only affects the tourism sector directly, by changes in temperatures or extreme weather events, but also indirectly as it will transform the natural environment that attracts the tourist in the first place (Becken and Hay, 2007). Changes in water availability, biodiversity loss, reduced landscape aesthetics, altered agricultural production (e.g., food and wine tourism), increased natural hazards, coastal erosion and flooding, damage to infrastructure and the increasing incidence of vector-borne diseases will all impact tourism to varying degrees. In contrast to the varied impacts of a changed climate on tourism, the indirect effects of climate induced environmental change are likely to be largely negative (Simpson et al., 2008).

Furthermore, national or international mitigation policies, such as the air tax recently introduced in the Netherlands, may have an impact on tourist flows (Gössling et al. 2008). They are likely to lead to an increase in transport costs and may foster environmental attitudes that lead tourists to change their travel patterns (e.g., shift transport mode or destination choices).

All these developments could have a major impact on some economies. About 10 percent of world GDP is now spent on recreation and tourism. Climate change will probably not affect the amount of money spent, but rather where it is spent (Berrittella et al., 2006).

The Netherlands
The temperature rise will possibly ensure an improvement in, and an extension of the summer season in northern Europe and an increase in the tourist and recreational activities that take place out of doors.
The Netherlands may become more attractive to foreign tourists in terms of climate and the Dutch population may also be more inclined to spend their holidays in their own country as a result of the improved weather. Climate change could lead to a strong growth in the demand for recreational and nature areas (MNP, 2005). The water-storage areas that will be developed could offer additional recreation and water-sports opportunities.
However, at the same time, climate change will also cause some negative effects. First of all, the increasing temperature might lead to a deterioration in the quality of swimming water (if no extra management measures are taken) due to, for example, an increased blooming of (toxic) blue algae; this can pose a threat to the health of swimmers. Furthermore, it will ensure a rise in sea level and lead to increased erosion of the beaches and dunes. Considerable efforts will be needed to raise the sand level of beaches so as to maintain their breadth – if this indeed proves to be possible. Tourism in the coastal areas could therefore either benefit or lose out as a result of climate change (MNP, 2005).
Finally, higher temperatures during the winter will result in less outdoor ice-skating opportunities. Although, in general, the economic importance of such activities is low (apart from the '*Elfstedentocht*') this will nevertheless result in a loss of Dutch tradition.

Adaptation
For many decades, most European citizens are used to taking long holidays during summertime and spend some of that time abroad. Originally, summer holidays were organised to enable the children to work on their parents' farm. This is one of the factors that cause seasonality in tourism. According to Amelung et al. (2007) seasonality is in general caused by institutional factors, such as summer holidays and religious holidays, and by natural factors. As described above, it is expected that the natural factors in Europe will change. The temperature in the Mediterranean region will rise for example during summertime. However, during spring and autumn the climate could still be very pleasant for tourists. The crucial question is the extent to which the demand side can adapt to or take advantage of these climatic improvements in the shoulder seasons, and, to what extent institutional seasonality can be overcome (Amelung et al., 2007).
If the intention is to attract more tourists during summertime to the Dutch beaches, then it will be important to maintain them and to invest in sand supplements.

Knowledge gaps
When considering climate change and associated changes in tourism there is a lack of insight regarding various issues. Knowledge on the future demand for different types of recreational land use, and the extra benefits in the Netherlands of increased tourism in summertime is largely absent. The latter would give insight into whether the accessibility and capacity of locations nearby water need to be improved. Another important question is what would be the most suitable locations to combine water management measures, such as water storage, with recreational activities. In Chapter 4 we will formulate research challenges based on these knowledge gaps.

2.4 Urban Areas

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).

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).

Adaptation

When building new residential areas, or when renovating existing areas, it is important to reckon with future climate change. First of all, building in higher areas would cause significantly less water nuisance for the dwellers. When developing new residential areas in the lower part of the Netherlands it is possible to heighten them by building on man-made hills. The shallow North Sea has enough and relatively cheap sand available for this purpose (van der Meulen et al., 2007). According to Aerts (2008), most home-owners are willing to pay for the extra costs. Furthermore, the concept would allow for multifunctional land-use such as underground transport lines. His research also points out possible new spatial patterns that may arise from such strategies.

In cities, sufficient green (areas) can improve the outdoor city climate. According to Chen and Wong (2006), the cooling impact of parks is reflected not only in lower temperatures in the parks themselves but also the lower temperatures in the nearby built environment. In addition, a study by Sonne and Viera (2000) showed that the temperatures measured during summer months within a residential area with extensive planting were constantly lower than a similar area with very few trees.

Furthermore, city water management should be adjusted, including adequate sewage systems and water storage areas to deal with future precipitation patterns. The creation of open structures during the development of new residential areas could also increase the circulation of fresh air, thus improving air quality.

Concerning the indoor climate of houses and offices, it is important to take into account climate changes without increasing the use of (fossil) energy. Passively cooled and low-energy office buildings, for example, can offer high thermal comfort even without using active cooling systems and/or air-conditioning systems. One promising approach to condition those buildings in summer employs utilisation of the building's thermal storage activated by natural heat sinks (e.g. ambient air, ground water or soil) through night ventilation or thermally activated building systems (Pfafferott et al., 2007). In addition, such (underground) thermal storage could also be used to store (solar) heat during the summer, which can then be used to heat buildings in winter time (Karacavus and Can, 2009).

Knowledge gaps

Increasing temperatures may lower labour productivity and the quality of life in urban areas. In this light more insight is needed into the costs and benefits of improving climate indoors in terms of labour productivity. With respect to urban areas, the costs and benefits of more greenery in order to deal with the urban heat island effect and extreme precipitation are largely unknown. An increase in extreme precipitation occurrences could furthermore disrupt transport and logistic processes, with possible consequences for the attractiveness of cities as places to work and live. Finally, climate change may have health implications, especially in urban areas. Associated changes in terms of where people would like to work and live are largely unknown.

2.5 Transport and Infrastructure

General[3]

To date the consequences of climate change and changing weather conditions for the transport sector have received relatively little attention in the literature. Still, it is widely known that transport systems on the whole perform worse under adverse and extreme weather conditions. This is especially true in densely populated regions, such as many coastal areas around the globe, where one single event may lead to a chain of reactions that influence large parts of the transport system.

Climate change may impact the transport system in various ways. On a global scale especially the increase in temperatures can influence patterns in tourism (see, e.g., Amelung and Viner, 2006; Nicholls and Amelung, 2008) and skiing holidays (see e.g., Elsasser and Bürki, 2002; Scott et al. 2001), plus the associated changes in passenger transport. We may also expect global shifts in agricultural production (see, e.g., Easterling et al., 2007; Fischer et al., 1994, 2002), with associated changes in freight transport. The predicted rise in sea levels and the associated increase in frequency and intensity of storm surges and flooding incidences may furthermore be some of the most worrying consequences of climate change, especially for coastal areas. Empirical research for Europe is limited, but research for the US East Coast and Gulf area shows that the effects on transport and transport infrastructure may be substantial (see, e.g., ICF, 2008; Jacob et al., 2001; Kafalenos and Leonard, 2008).[4]

Regarding the impact of climate change and adverse weather on road transport most studies focus on traffic safety, congestion, and traffic volume. With respect to traffic safety by far the most important variable is precipitation, most studies finding that precipitation increases accident *frequency* (see, e.g., Chung et al., 2005; Shankar et al., 2004), but decreases accident *severity* (see, e.g., Andrey et al., 2003; Eisenberg and Warner, 2005). The mediating effect here is probably that precipitation reduces traffic speed, thereby reducing the severity of accidents when they do occur. With respect to congestion most studies show a reduction in traffic speed due to rain and especially snow (see, e.g., Hranac et al., 2006; Sabir et al., 2008b; Unrau and Andrey, 2006). Interestingly, precipitation appears to have a negative effect on traffic speed, especially during peak hours. Finally, although the available empirical evidence shows that during days with adverse weather, and especially precipitation, inessential journeys may be postponed or shortened, the magnitude of the effect depends to a substantial extent on the intensity of rain or snowfall (see, e.g., Al Hassan and Barker, 1999; Keay and Simmonds, 2005). Furthermore, there is some evidence that adverse weather matters more for leisure trips than, for instance, commuter journeys (see Chung et al., 2005; Changnon, 1996). With respect to the inland shipping sector, changes in temperature and precipitation have consequences for riverine water levels. Low water levels will force inland waterway vessels to use only part of their maximum capacity, which will considerably increase transportation costs in the future (see, e.g., Millerd, 2005; Olsen et al.; 2005). Weather also plays a crucial role in the aviation sector. Kulesa (2002) estimates that poor weather causes 70% of all delays in US air transport while also being an important contributing factor in 23% of all aviation accidents. Figures from the National Transportation Safety Board also show that adverse weather has an increasing effect on aircraft accidents, especially those with fatalities (see Changnon, 1996). The total annual monetary costs associated with accident damage and injuries, delays and unexpected operating costs are estimated at $3 billion in US aviation (Kulesa, 2002).

The Netherlands[5]

With regard to the Netherlands the potential effects of climate change resemble those on a global scale, although some issues deserve special attention. Sea level rise is obviously an issue of major concern. Despite the fact that there have been no studies on the impact of SLR on transport and transport infrastructure in especially the western part of the Netherlands, the report by the Deltacommissie (2008) suggests that important challenges need to be met.[6] It is clear that sea level rise may have clear implications for the Port of Rotterdam. Although these implications have been acknowledged by the port authorities, the current expectation is that potential adaptations do not necessitate a separate approach (see Van Ooststroom et al., 2008). For the aviation sector, and especially Schiphol airport, wind speed and wind direction have obvious effects on safety and delays and cancellations. This may have large cost implications, both for the airlines and the travellers. In a country like the Netherlands it is important for airports that sufficient runway capacity is available under different wind directions. Underestimation of

[3] A more extensive overview of the impact of climate change and adverse weather on the transport sector is available in Koetse and Rietveld (2008).

[4] Dasgupta et al. (2007) assess the impact of sea level rise for coastal areas in 84 developing countries.

[5] An assessment of climate change impacts on the transport sector with a focus on the Netherlands is provided in Koetse and Rietveld (2007).

[6] A study by AVV (2006) shows that the economic costs associated with the mobility effects (delays and rerouting) due to a single flooding incident in the Netherlands may be substantial, ranging from € 414 million to € 1.1 billion in 2010.

wind speeds and their directions may mean that wrong decisions are taken on the design of airports in terms of runway capacity and orientation. CPB (2002) has considered various airport configurations for an airport like Schiphol. It has estimated that when the runway system would be 'wrongly' configured in terms of dominant wind speeds, it would lead to an unnessary inefficiency in the use of the airport. The loss of hours during which the airport can be used in an operational way sums between 300 million and 1 billion Euro. However, implications of climate change on wind speed and especially wind direction are highly uncertain.

Changes in weather conditions due to climate change, especially the increase in temperature and the changes in precipitation patterns, will influence competition between different transport modes, both within passenger and freight transport. The net effect of future changes in weather conditions on road transport is ambiguous (see Koetse and Rietveld, 2007). Although average rainfall may decrease, extremes are likely to increase, making the consequences for congestion, traffic tailbacks and traffic accidents uncertain, both in terms of direction and magnitude. Moreover, increases in temperature will decrease the probability of snowfall, thereby decreasing congestion further. With respect to rail transport, Duinmeijer and Bouwknegt (2004) show that weather appears to cause approximately 5% of all infrastructure failures in the Netherlands in 2003. Most of the weather-related failures are caused by high temperatures, icing, storm and lightning. In this respect the effects of climate change are again ambiguous, increasing failures due to high temperatures and decreasing failures due to icing. Finally, climate change scenarios for Western Europe show that the incidence of low water levels will increase, implying increased costs for the inland navigation sector (Jonkeren et al., 2007). Ultimately, the consequences of climate change-related changes in weather conditions are ambiguous for most transport modes, implying that the consequences for the competitive positions of the various modes in passenger and freight transport are uncertain. However, with respect to the inland shipping sector Jonkeren et al. (2008) show that, although the increase in costs due to climate change may be substantial, consequences for the competitive position of the sector appear to be limited.

Adaptation

It is likely that adaptation to increased risks of flooding damage in the transport sector is to a large extent incorporated in adaptation to the general increased risk of flooding. Shifts in freight transport due to changes in global and regional agricultural production patterns are unknown for the Netherlands, but are likely to present opportunities rather than risks. Increased passenger flows due to increased tourist activity under higher temperatures, which will likely be concentrated in cities and along the coast, may necessitate changes in the capacity and locations of parking facilities and changes in public transport.

Although it is clear that increases in temperature and changes in precipitation patterns due to climate change will affect transport infrastructure in various ways, it is not clear in which direction and to what magnitude. Which adaptation measures, if any at all, are necessary or efficient and to what extent, is therefore difficult to judge. One of the weather changes that stands out is the increase in frequency and intensity of extreme weather occurrences, especially in terms of precipitation. For road and air transport, and to a lesser extent for rail transport, this will imply a substantial increase in disruptions. It may be efficient for adaptation measures to focus on mitigating these consequences.

A possible adaptation to the negative climate change consequences for the inland shipping sector at the infrastructure level may be to dredge at crucial bottlenecks and additional staunching. Another potentially effective adaptation is the more accurate prediction of water levels, such that safety margins between keel and river bed can be reduced. With respect to the private sector, frequently mentioned adaptations are using smaller ships and lighter materials.

Obviously, the attractiveness and economic efficiency of a specific adaptation to climate change depends significantly on its costs and its potential benefits. In this light, the numerous uncertainties associated with climate change and its consequences may make it worthwhile to wait for more information before potentially costly and potentially unnecessary or even wrong adaptation measures are taken.

Knowledge gaps

Several knowledge gaps can be distinguished with regard to the impact of climate change on the transport sector. The effects of climate change on the aspect of reliability of the various transport modes are probably negative, but the extent to which is unknown. Furthermore, it is interesting to investigate the impact of extreme weather occurrences on infrastructure disruptions and transport costs? A relevant related question here is what would be the long term effects of these changes in relative costs on the competitive position of the various transport modes in passenger and freight transport. With regard to air transport it is also crucial to identify the impact of wind strength and wind direction on the design of Schiphol and other (regional) airports. Finally, especially relevant for the Netherlands is that we gain an insight into the long term consequences of climate change for the Port of Rotterdam connections to the inland areas, including inland waterway transport.

2.6 Water safety

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, 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.

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 physical and chemical processes, so 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.

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).

The effects of flood

The effects of flood can be divided into direct and indirect effects. Direct effects are related to physical damage to, for example, buildings, vehicles, infrastructure, crops or persons, etc. Indirect effects are those effects that also have an impact outside the flooded area, such as disrupted transport systems or a lack of certain goods (TNO 2008).

The new Delta-committee (Deltacommissie, 2008) distinguishes four important goals in relation to water safety and flood risk: to protect human beings, to protect economic, ecological and cultural values, to prevent damage to the international reputation of the Netherlands and to prevent disruption of our society (Deltacommissie, 2008). This implies that both the direct and indirect costs of flooding inside and outside the dykes should be taken into account, as well as the monetary value of landscape, ecological and cultural damage, damage to the international reputation and the costs of societal disruption. The latter two in particular are difficult to assess and are not extensively defined in the literature.

The economic damage is often estimated by using a (social) cost-benefit analysis similar to the one used for infrastructure projects. A land-use model, such as the Land Use scanner (see section 3.3), can be used to determine which of the economic activities and land-use categories are the most likely to be affected in the different scenarios. To estimate the indirect effects of floods a general spatial equilibrium model, such as RAEM could be used (TNO 2008). Socio-economic optimisation provides a design criterion that reflects the societal capacity to commit resources to sustainable risk reduction. Details of financing have a major influence on the design of flood control projects by socio-economic optimisation; since future life risk must be discounted like finances, the interest rate and amortisation period influence design decisively[7]. Furthermore, flood control facilities have typically long design lives, spanning many generations; therefore an important issue is how the financing, including the costs of risk mitigation, could be distributed fairly over generations (Lind et al., 2008). In addition, more insight into budgets and capacities of authorities, both now and in the future, is also required.

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 can be found on this topic.

[7] This 'discounting' of a future risk does not mean that it is considered less worthy of risk mitigation. It means simply that $1 today can be invested—or borrowing it can be deferred—to grow to a greater value in the future (Lind, 2007).

Adaptation
Adaptation to climate change in water management can be assessed in many different ways. One important aspect, however, is flood protection. Flood protection structures can be either artificial, such as dykes and dams, or natural, such as retention areas. Furthermore, according to van Gelder (1999) measures that can be taken to reduce the risk of flooding can be subdivided into contributions through water management, spatial planning, nature protection and agriculture and forestry.

Artificial structures
Artificial structures are generally the responsibility of water management organisations. The most important artificial structures are the already mentioned dykes to protect from the sea and rivers, and storm surge barriers to protect from the sea. One disadvantage of dykes and dams when used near rivers is that they can unnaturally constrict rivers within a narrow channel, causing the waters to rise higher and flow faster than they otherwise would. This leads to more powerful and rapid flooding. Furthermore, they can give a false sense of safety.
According to the Deltacommissie (2008), the safety level of dykes in the Netherlands should be raised in the near future. Therefore, the concept of 'delta-dykes' is proposed: dykes that are broad or high enough to prevent unexpected and uncontrolled flooding. Depending on the local specific situation, those dykes can be very high, very broad or very strong (with extra fortification inside). In particular the idea of very broad dikes (300 m) allows the integration of flood protection with other activities such as housing, recreation and agriculture.
A measure used to protect the seacoast is to supplement the beaches with additional sand. Today, coastal nourishment is a widespread soft engineering option in the North Sea region, and intensively used in the Netherlands to maintain the base coastline of 1990 (Safecoast, 2008). In the future this could be used to broaden the existing beaches to make them more resistant to the rising sea level (Deltacommissie, 2008).
An often mentioned, multifunctional protection structure is the development of new islands off the Dutch coastline. These islands are supposed to reduce the power of waves and reinforce the coast fundaments. They could be combined with other (land-use) functions such as nature, recreation or energy production. However, it is not yet clear what the exact costs and benefits are (Reijs, 2008) and also the Delta committee is not in favour of this idea.

Natural structures
Besides the artificial protection structures, natural structures are becoming increasingly important. In 1993 and 1995, the water levels in the rivers were extremely high which resulted in the massive evacuation of people. Fortunately the dykes held there own but it was clear that a new flood protection approach was needed. The decision was therefore made to find a way for rivers to cope with greater volumes of water in a safe way. In 2006 the Cabinet drew up the Spatial Planning Key Decision (SPKD) Room for the River. The basic measures consist primarily of actions aimed at creating more space for the river and lowering high water levels, such as deepening river forelands, relocating dykes further inland, lowering the groins in the rivers, depoldering, creating flood channels and enlarging summer beds. The reinforcement of dykes is included only if other measures are too expensive or inadequate.
Most of these measures require space that now lies inside the dykes. In many cases, the measures will not be implemented for several years. Until that time, to ward against developments that could interfere with the river expansion plan, these areas have been set aside in the SPKD Room for the River (Ministry of Transport, Public Works and Water Management, 2006).
Apart from Room for the River measures, temporary measures can also contribute to water safety. An example is pointing out retention areas. In the UK, recent reforms of rural and agricultural policy and a new strategic assessment of policy for flood risk management are shaping new approaches to flood risk management in rural areas in the future. Partly in response to widespread flood occurrences in 2000, Making Space for Water (Defra, 2004) identified, among other things, the potential contribution of rural land management to the management of flood risk. This includes measures to control runoff from farmland, retaining water on farmland in the higher parts of catchments as well as storing it on floodplains in the lower parts of catchments (Posthumus et al., 2008).
However, the discussion about the risk of flooding in flood plains is a delicate topic in agricultural circles. On the one hand, the use of land as an excess water retention area guarantees that there will be no other developments competing for the limited available space, such as residential housing or the construction of motorways. On the other hand, farmers have to deal with the uncertainty about the future of their farm. Subsidies can be provided for this, or inconvenience could be compensated by a one–off payment (Brouwer and van Ek, 2004). When the retention areas are used for nature, these problems are less significant.
Spatial planning instruments

Apart from these artificial and natural measures, water safety can also be improved through the use of spatial planning instruments. An important task of spatial planning is to protect existing and potential runoff and storage areas, to keep areas subject to the risk of flooding free of undesirable developments and to integrate water streams in urban development (van Gelder, 1999). An important issue in this respect is whether the construction of buildings should be allowed in flood plains and how they should be protected. Furthermore, efficient warning systems that can adequately predict high water levels could be very useful.
Another relevant dimension is that given the uncertainties on future climate change spatial reservations may be needed to set-aside particular areas. In the future, when more knowledge becomes available on these areas, they can actually be used in safety strategies without major transition costs.

Water storage
Water storage is a spatial strategy that can be used for many purposes. First of all, as described above, it can temporarily lower the water level in a river to prevent flooding. Those areas can most of the time be used for agricultural activities, for example, but when the rivers contain too much water, they could be used to temporarily store water in order to lower the water level of the river. However, this measure is only efficient when the retention areas are located near the place where problems could arise. As this is usually in the vicinity of urban areas, the selection of adequate retention areas can be difficult.
Another important objective in build-up areas is to retain precipitation water. Due to the increased hard surfaces in cities, such as roads and buildings, rain water flows off very quickly resulting in dry subsoil and the increased probability of flooding elsewhere. A related issue is the overflow of untreated wastewater following heavy rainfalls, which is a major source of pollution to the receiving rivers (Semadeni-Davies et al., 2008). Therefore, it is important to retain the water as much as possible by allowing it to infiltrate into the soil and by using water bodies in which to store the water. During dry periods, this water can be used to water urban green areas. Finally, in more rural areas, water storage can be a buffer for nature and agriculture in dry periods.
If well planned, integrated water management can provide benefits in many ways. It can increase the space available for species, create opportunities for the development of new nature areas and contribute to expanding the ecological corridors thus enabling the migration of species. Indirectly, integrated water management can help to counteract flooding and drought and thus can prevent damages to the ecosystem. Moreover it can be used for recreational purposes.

Knowledge gaps
When thinking about flood protection, first of all the timing of measures is very important, as are the consequences of the irreversibility of certain developments. A clear knowledge about this is currently lacking. Furthermore, insights are also lacking in the costs involved in floods, related *inter alia* to the indirect costs of floods and the ways in which businesses perceive these costs. Related questions in this respect are what is an acceptable flood risk and how , for example, does it relate to acceptable traffic risks. Related to the costs and benefits of flood protection the questions include how can flood protection be combined with other activities in the most efficient and sustainable way, how the costs of a disrupted society or damage to the national reputation of the Netherlands can be estimated, what are the costs of set-aside land, and what are the best ways to temporarily use set-aside land. Other crucial questions are how a shortage of fresh water, due to the infiltration of salt water, in certain regions of the Netherlands will affect the price level of freshwater, and how this might affect the economic activities that are dependent on it. Finally, research is needed into the role of incentive structures to arrive at an appropriate balance between public and private sector efforts in adaptation.

2.7 Other activities

Businesses
Adaptation to climate change in the business sector is not a generalised process. Although some proactive companies have started to integrate climate-related considerations into their strategic decision-making, most businesses do little more than comply reactively with minimum standards and regulations (Bleda and Shackley, 2008).
As the Stern (2007) report observed, one of the main problems that policy makers face is that by the time climate change is apparent with a higher level of certainty, it will be too late to reverse its effects or to effectively undertake adaptation. The challenge then is to ‘convince’ businesses that climate change is actually underway and will have repercussions for their activities. The long-term success of policies directed to reduce harmful emissions, and encourage adaptation processes depends greatly on making businesses aware of what they are potentially up against, and of the opportunities that present themselves from early adaptation.

Consequently, a good understanding of the way business organisations perceive climate change and where they stand in terms of adaptation to its impacts is highly relevant, not only for practitioners and academics but also for policy makers (Bleda and Shackley, 2008). An important dimension of adaptive behaviour would be that firms may in the long run reconsider their location strategies, implying the possibility of differential regional growth rates. In particular the safety reputation of regions may for certain sectors be an important lead factor in location decisions.

Energy

While the creation of a competitive energy market is favourable for the increase in economic growth, securing the energy supply, mitigating the environmental impact and the aspect of energy affordability are also important targets. Energy is connected to climate research mainly through the feedback of fossil energy consumption to climate change, through the emission of carbon dioxide and, more recently, through the increased demand for bio-energy. These topics are well covered in scientific literature.

From a spatial economic point of view, especially bio-energy and biofuels are interesting. Bio-energy is a relatively new topic that is rapidly becoming controversial as its claim for good agricultural land may limit the earth’s potential to feed its population. Nevertheless, the EU's renewable energy roadmap sets binding targets for the share of biofuels (10%) and renewable energies (20%) in the total fuel and energy consumption by 2020. The Commission’s Biomass Action Plan expects a potential increase of energy crops from agriculture from 2 MTOE in 2003 to 102-142 MTOE in 2030 (EC, 2006). The production of biofuels corresponds to a mono-cultural production pattern. The economic incentives involved are sufficient to bring land out of set-aside areas, and these set-aside areas often have a targeted biodiversity function. The biofuels-related policies can therefore significantly influence land-use changes and biodiversity (Eickhout et al., 2008). Furthermore, food shortages as a consequence of a rush on energy crops can be expected without clear benefits, since the claimed greenhouse gas reduction could be limited. In addition, the fluctuation of energy-prices complicates the estimation of benefits from bio-energy.

For biofuels based on energy crops, the potential effects of extra land use for agricultural activities might lead to several positive and negative effects, not necessarily in the Netherlands because most of the cultivation is expected to take place abroad. In the case of biofuels it is interesting to note that the Dutch Government has for many years shown to be reticent in supporting new initiatives using 1st generation options. The agricultural lobby has not been as strong as in other European countries (Ros et al., 2009).

An important issue in the Netherlands is to keep the production of electricity up to the required level in periods of high temperatures and low river water levels. As mentioned earlier, this can result in problems for the cooling processes that take place in most power plants. Moving power plants to the coast, to cool them with sea water could be an effective solution (van Ierland et al., 2007).

Knowledge gaps

A knowledge gap in this field concerns the question how business organisations perceive climate change, and where they stand in terms of adaptation to its impacts. More in particular, the implications of shortages of cooling water for Dutch power plants can be mentioned as an issue.

3. Spatial Economic Analysis

The transformation of land use and land cover is driven by a range of different factors and mechanisms. Climate, technology and economics are key determinants of land use change at different spatial and temporal scales. In addition, as mentioned earlier, uncertainties about the level, as well as the wide range of effects that could be caused by climate change make it difficult to assess impacts on society from a spatial economic point of view. A first important reason for this is the different levels at which climate change is manifested. The temperature, for example, is expected to rise world-wide but local differences will be significant. In addition, local impacts will vary to a large degree due to different biophysical and geomorphologic differences. Another example is the effect of rising water levels. Not only will rising water levels have different positive or negative effects due to the different morphologic characteristics (such as elevation), but the impact will also differ due to different levels of investments. Kind (2008), for example, estimated the amount of investments needed to reach an optimal flood safety strategy and he concluded that the bandwidth was actually 100 per cent.
Another challenge is to deal with different time scales of developments and effects. Different processes, especially when making a distinction between socio-economic and biophysical processes, take place in different time frames. Economic processes are to a large extent explained by profit maximising behaviour and take place on a long time scale, whereas physical processes are generally well captured with spatially explicit simulation rules using short time intervals. This makes it very difficult to integrate them into one comprehensive model.
All the uncertainties and variety of forces and variables make it extremely difficult to simplify the situation to fit a specific model. Therefore, scenarios are often used to deal with uncertainties and bandwidths. However, when decisions need to be made, the scenarios or different alternatives need to be compared and evaluated. Tools frequently used are cost benefit analysis (CBA) to deal with monetary issues or multi criteria analysis (MCA) to take into account a wider range of different aspects. The question is, to which extent are these kinds of existing tools useful to assess the impact of climate change on economy and space. In addition, in order to understand the mechanisms of change in the use of land and the impact of policies, researchers and practitioners have turned their attention to formulating, calibrating and testing of models that simulate land use dynamics. These land use change models help us to understand the characteristics and interdependencies of the components that constitute spatial systems. In this part of the report we describe scenario analysis, CBA, MCA and land-use models as tools in assessing the impact of climate change on the spatial economy.

3.1 Scenarios

Scenarios have become a respected and powerful tool in modern policy analysis, in both private and public domains. They are particularly useful in decision and policy situations that are characterised by a high degree of future uncertainty (with often structural or systematic changes in the context or in the functioning of a relevant policy system). Instead of deterministic, stochastic or blueprint planning techniques for short to medium-term policy issues, scenarios are operational tools for complex decision making that is marked by long-term and largely unpredictable uncertainty where visioning on future developments is necessary. Scenario analysis is then a knowledge-based rational tool to explore uncertain futures, with the aim to respond properly to future challenges. It is a learning tool (‘flight simulator’) that serves to arrive at informed and accountable decisions and/or solution trajectories. It does not aim to identify the best possible future, but to design a rational and transparent mechanism for coping with uncertain futures. Given a set of alternative images of the future, a scenario serves to shape conditions to improve future perspectives, to prevent the emergence of disadvantageous effects of undesirable futures (or to ameliorate harmful effects), to exploit new opportunities associated with systemic changes in the future, and to cope with events that may form impediments to the achievement of future goals (van Leeuwen and Nijkamp, 2007).

Scenarios versus conventional forecasting methods
Scenarios differ from conventional methods of policy analysis and strategic planning *inter alia* in that uncertain roads to reach a situation are explored. They not only extrapolate current trends, but offer a set of different pictures, describing possible futures and the paths to it in a consistent way. Table 2, summarises the features and differences between conventional methods and scenarios.
There are many different kinds of scenario approaches. Descriptive scenarios, for example, are mainly based on know-how about past and current trends. Apart from conventional wisdom, no major changes are assumed. Normative scenarios, on the other hand, focus more on the desirability of a development or choice (for example by using norms and values from stakeholders or respondents). In this way, several - sometimes contrasting - scenarios can be constructed.

Furthermore, scenarios can be based on forecasting, starting with the current situation which, together with the impact of future trends, leads to a future image. These are so-called projective scenarios. Another approach is used for prospective scenarios, which are based on back casting, in which first the situation in the future is described, while next the paths (e.g. policy measures or societal changes) to it are presented. In this way, there is more room for imagination and an open mind.

Table 2: Features and differences between conventional methods and scenarios

	From (conventional methods):	**To (scenarios):**
Starting point	Reactive problem driven From present to future Model-determined mind	Proactive vision driven From future to present Alertness to signals of uncertainty
Focus	Focus on quantified variables More emphasis on details Deterministic analysis Single-track thinking	Focus on qualitative pictures More emphasis on trends Creative thinking Multi-track thinking
Process	From simple to complex From quantitative to qualitative Statistical-econometric tests Multiple implicit assumptions	From complex to simple From qualitative to quantitative Plausible reasoning Transparent (simple) assumptions
Results	Results determined by status quo Closed future Limited set of options	Results based on future images Open future Open range of options

Source: after Nijkamp et al., 1998

Scenarios and Climate Change

Scenarios have gained in popularity during the last decade. Companies facing strategic investment decisions, such as oil companies or financial conglomerates, have developed scenarios to think through their decisions in different futures (de Mooij and Tang, 2003). An advantage is that scenario analysis can be applied at many different geographical levels.

In climate change research, scenarios are extensively used, particularly because there is so much uncertainty. Usually, the scenarios exclude outlying ‘surprise’ or ‘disaster’ scenarios in the literature. Furthermore, as the IPPC (2000) states, any scenario necessarily includes subjective elements and is open to various interpretations.

The four climate scenarios for the Netherlands, developed by KNMI, show likely pictures of climate changes in 2050. The results of a large number of (climate) models was used to build these scenarios, which are descriptive, projective and knowledge based. However, because of the uncertainty in future demographic, economic, technological and social developments and the associated emissions of greenhouse gasses it is not possible to show a single (likely) future. Therefore the KNMI developed four different scenarios with different worldwide temperature rises and different air current patterns (KNMI, 2006).

Even more uncertain than long-run developments in, for instance, demography, ICT and individualisation are the responses to them by societies. Therefore, for example, the CPB developed scenarios which are defined by different levels of international cooperation and by the mix of public and private responsibilities in European countries. Combining these uncertainties leads to four different scenarios: strong Europe, global economy, regional communities and transatlantic markets. The scenarios are used to provide a structure for discussing the uncertain future of Europe in a comprehensive framework. In this way, the scenarios may yield early warnings to policy makers about particular challenges in the future, e.g. with regard to necessary reforms of the public sector and the need for effective international cooperation. Second, the scenarios serve as a tool for policy analyses with a long-term character (de Mooij and Tang, 2003).

The development of these scenarios differs slightly from that of the KNMI scenarios. First the strategic policy questions that needed to be explored were selected. When the relevant key uncertainties were defined, four possible futures could be described. After the formulation of story lines that shape the four futures, the developments were translated into variables that appear in a computable general equilibrium (CGE) model for the world economy, called WorldScan to quantify the characteristics of the different scenarios (de Mooij and Tang, 2003). However, not only socio-economic scenarios are developed this way, also the IPPC scenarios started with four different narrative storylines (based on an extensive literature review) to describe consistently the relationships between emission driving forces and their evolution and to add context for the scenario quantification (IPPC, 2000).

The purpose and advantage of scenarios is that they can be seen as a structured brainstorming technique, which may widen the perceptions of researchers and policymakers regarding future possibilities and their impacts. However, they are constrained by various factors, as they have to be relevant to the policy issues at hand, have to find their roots in the current situations with a complex force field, have to design logical transition trajectories between the present and the future, have to be internally consistent, and have to be based on the current sate-of-art knowledge. When using scenarios to analyse the socio-economic effects of climate change two kinds of scenarios are necessary: climate and economic scenarios. First of all, economic changes develop faster than climate changes. But more importantly, future economic developments will affect climate change; this means that there are interactions and interdependencies between the two kinds of scenarios which can complicate further analyses. Finally, scenario analysis will not remove the uncertainties but merely make the effects of uncertainties explicit.

Knowledge gaps
Important knowledge gaps in this field deal with how the definition and parameterisation of scenarios can be enhanced in order to truly integrate climatic and socio-economic change in a quantitative, spatial manner? Furthermore, more insight is needed in the optimisation of the usability of scenarios in actual planning processes. How can we move beyond the production of interesting images to link them to actual decisions and strategies? What other (combinations of) methods can be used to incorporate uncertainty in planning processes?

3.2 Evaluation of alternatives and strategies

Cost Benefit Analysis
The standard framework for evaluating policies and investments from an economic perspective is Cost Benefit Analysis (CBA). The theoretical foundations for CBA were laid by Dupuit, a French engineer. In 1844 he introduced the concept of consumer surplus which has since played a crucial role in welfare economic theory (Vreeker et al., 2006).
The basic concept in welfare economics is known as the Pareto principle. This principle comprises the idea that a policy measure is socially desirable if every member in society is made wealthier, or at least that no member is made worse off. Unfortunately, the Pareto criterion is useless when there are both winners and losers. To overcome this problem, the compensation principle was introduced: winners should be able to compensate the losers.
The aim of CBA as an evaluation instrument is to locate and include all the costs and benefits of a project and to express the unobservable change in social welfare in observable monetary units (Varian, 1992). Today, this method is extensively used for the economic evaluation of all kinds of projects, in particular for transport infrastructure projects (see also the OEI guidelines). Of course, not all costs and benefits are easily expressed in monetary terms, this is always a difficulty in the evaluation of projects. Therefore, the inclusion of unprized effects, such as environmental effects, requires the monetary valuation of these effects. Since no market - and thus no market-prices - exists for these goods, various valuation methods haven been developed, such as revealed preference techniques (Verhoef, 1999).
An extension of CBA is a Social Cost Benefit Analysis (SCBA). The aim of a SCBA is to compare policy alternatives in order to be able to evaluate the relative performance of the alternatives compared to a reference situation. Central are the assessments and preferences of consumers. By doing so, a broad definition of welfare needs to be used, not only including consumer products that can be bought in a shop (on the market) but also products such as leisure time or safety. Of course, it is generally very difficult to measure the cost and benefits of such products.

CBA and Climate Change
An early application of costs benefit analysis to adaptation measures is done Van Dantzig (1956) who addresses the issue of optimal dyke heights after the large flood in 1953 that caused some 1800 casualties in the Netherlands. One of the best known CBAs related to climate change in the mitigation domain is the so-called ‘Stern review’ (Stern, 2006). The Stern Review on The Economics of Climate Change is one of the few cost-benefit analyses of climate change to come out in favour of immediate and decisive action to reduce greenhouse gas emissions. However, this review received massive criticism, for example, for not tackling the issue of non-substitutable loss of natural capital (Neumayer, 2007), for mistreating extreme events (Pielke Jr., 2007) or for its assumptions about the (future) discount rate (Nordhaus, 2007).
In general, it is acknowledged that (quantitative) CBA has its limitations in climate policy (van den Bergh, 2004). A first challenge, in order to undertake a CBA, is that a concrete change, scenario or project needs

to be defined. This can cover a reduction of greenhouse gas (GHG) emissions, a climate change, or a combination of these alternative futures. Since the benefits of climate policy are the avoided costs of climate change, regardless of the scenario, the potential climate change needs to be known. However, there is considerable uncertainty about each phase of the cause–effect chain. Another limitation is that often in a CBA, extreme and irreversible events are either not or unsatisfactorily taken into account. Finally, there is the previously mentioned problem of discounting. The fundamental question is whether individual and intra-generational discounting can be extended to a context of public investments and inter-generational effects. An argument against this is that a society, as opposed to an individual, does not have a finite life, and hence no time preference, which is the ultimate basis of discounting. These critiques indicate that social cost benefit analysis should be applied in a careful way in the context of climate change. A closer look at the debate also shows that applying this tool has fewer problems in the domain of adaptation strategies compared with mitigation.

In the Netherlands all larger (spatial) projects are required to carry out an environmental impact assessment which describes several alternatives of the project using SCBA. Therefore, there is considerable experience in estimating the costs of increasing travel times, of emissions of harmful matter such as NOx or of fatal accidents. There is also a tendency to use SCBA increasingly in other spatial policy issues, such as water safety. The Deltacommissie (2008) explicitly uses a broad definition of water safety which is consistent with the broad welfare definition as used in SCBA. However, related to water safety, there is clearly a lack in knowledge about the different effects (both costs and benefits) of different policies.

One example is the value of statistical life (VOSL). This VOSL represents the total amount of money that a society is collectively willing to pay for a safety improvement that affords each individual in the society a very small reduction in the risk of premature death, but overall is expected to prevent one premature death (Leung and Guria, 2006). Much literature exists about VOSL in transport or labour sciences (e.g. de Blaeij et al, 2003; Shogren and Stamland, 2006), but not related to water safety. In addition, when flood accidents occur, often more persons are injured than killed, which means that also the valuation of non-fatal victims is an important issue. Other important issues about which more information is needed are the valuation of large groups of victims, the disruption of society or damage to the national reputation.

However, in designing an optimal strategy for e.g. flood protection, the social costs of investing in water defences have to be balanced against the social benefits of preventing damage by flooding. Because both in social costs and social benefits non-material issues are involved, the choice of safety standards is ultimately a political decision (Eijgenraam, 2006).

Multicriteria Analysis (MCA)

Multicriteria analysis (MCA) has been developed as a method to avoid problems with the valuation of external effects and distributional issues. This kind of analysis aims to take into account the heterogeneous and conflicting dimensions of decision problems. An essential difference between MCA and CBA is that CBA takes consumer preferences as the starting point and tries to achieve market conformity, while MCA does not model the preference of the main actor (often the government) as the sum of individual preferences but the main actor is assumed to have its own preferences and responsibilities (Vreeker et al., 2006). MCA has become a standard tool in environmental impact assessments in some countries including the Netherlands (Commissie MER, 2002).

MCA is a useful tool for evaluating and selecting several project alternatives , as well as for evaluating different policy perspectives, such as cost minimisation, minimisation of ecological damage, and maximisation of safety. Many of those perspectives cannot be achieved to the full extent at the same time as they may be more or less contradictory. MCA uses weights or priority levels assigned to both quantitative and qualitative evaluation criteria together with specific approaches which rank the alternatives. The weights of partial objectives and decision criteria are usually estimated by ranking or scoring methods where the weights of partial objectives and subordinated criteria are determined independently. The outcomes are not in the form of a valuation but more often in the form of a selection, a classification or a ranking of alternatives.

One important advantage of MCA is that it can consider a large variety of criteria, whether quantitative or qualitative, independent of the measurement scale. Hence, it allows for a more comprehensive analysis since it can include a wide range of aspects of the problem rather than being restricted to marketed goods or monetised costs and benefits (Vreeker and Nijkamp, 2005). Furthermore, MCA allows showing the effects of different preferences and weights in a planning process. Developing a weight matrix can be a clarifying process. However, this should be done in an open and transparent way; otherwise MCA could be a seen as a manipulative process. Therefore, the allocation of weights should be explicitly reasoned (Commissie MER, 2002). Among the disadvantages of MCA are that it can easily lead to double counting of certain effects, and that its results may be rather sensitive to the particular MCA method used.

MCA can be a useful tool for the evaluation of adaptation strategies to climate change as it aims at comparing different strategies with a baseline scenario. For the analysis, both quantitative and qualitative values can be used, which can make it easier to assess uncertainties.

Knowledge gaps

Most knowledge gaps in evaluation are related to uncertainties about costs and benefits. An important question in this respect is how to take into account the value of statistical life in water safety, and also the perceived costs of non-fatal accidents? Furthermore more knowledge is required about the costs of large disruptions in society or damage to the national reputation, as well as about how to discount the costs made now against benefits in the (far) future.

An interesting complementary tool could be agent-based modelling, which studies macro-level complexities from the interactions at the micro level (Ma et al., 2009). The question is to what extent this could be a useful tool to address, for example, agent heterogeneity or interaction effects – possibly combined with the field of optimisation modelling under uncertainty.

3.3 Modelling land-use change

Land-use models are complex by nature as they deal with both physical and socio-economic driving forces. On the one hand they include human decisions or choices, on the other hand spatial heterogeneity and the adaptive behaviour of crops and animals, as well as of soil and water systems. Currently, much research focuses on the modelling of the complex interrelations between changes in land-use and climate. The relationship between the two is interdependent: changes in land-use may impact the climate whilst climatic change will also influence opportunities for future land-use (Dale, 1997; Watson et al., 2000). The feedbacks of land-use change on the climate are typically modelled in global change models such as IMAGE (Alcamo et al., 1998; Eickhout et al., 2007), whereas the impact of climate change on local land-use patterns is the domain of spatially explicit models of land-use change (e.g. Koomen et al., 2008). The latter approach integrates sector-specific demands (for housing, agriculture, etc.) and land suitability for certain uses and provides an indication of the likely use at a specific location in the future under different climate conditions. It is this type of detailed local-level modelling of land-use patterns that is the objective of the current project.

Climate change modifies the mechanisms of the land demand-supply interplay as well as the boundary conditions and scenarios within which it unfolds. The main processes through which climate change and socio-economic developments may affect the interaction between the demand and supply of land are:

the physical modification of the suitability of certain areas for some uses of the land;

the modification of productivity and production processes within sectors such as agriculture, forestry, and nature;

changes to the primary functioning of the economy and society leading to a different set of policies that influence, for instance, economic development (growth) or the type of development (e.g. free market versus government);

the extra demand for space as a result of adaptation strategies within various sectors.

In order to accommodate these impacts, pro-active adaptation measures within the area of spatial planning are prerequisite to cope with climate change and will offer new opportunities for rearranging land-use (Parry, 2000a; Parry, 2000b). However, such rearrangements will pose challenges and conflicts between the national and regional policy levels, and between sectors. For instance, when problems concerning water storage and flooding are tackled with spatial rather than technical measures, the capital-intensive agricultural or urban functions of these buffering areas will be highly restricted (Borsboom-van Beurden et al., 2007).

Obviously, climate change is not the only factor driving land-use change. Socio-economic developments are another major driving force. In fact, these developments interact with climatic changes as was discussed before. For example, economic and population growth cause increased emission of greenhouse gasses, which influence the global climate. As a result, changes in annual regional rainfall patterns could impact agricultural production or cause the tourist industry to migrate to other regions. Prolonged periods of drought and other extreme weather conditions are other examples of climatic changes that impact the economy. Integration of climate change and socio-economic factors is, in our opinion, thus needed in any long-term study on future land-use configurations and related spatial planning measures. However, the scenarios used in most land-use allocation models, are usually neutral to climate change, as only socio-economic factors are taken into account. This assumption appears inappropriate in relation to the expected substantial climatic changes. Therefore, it is extremely important to combine projections of climate change and socio-economic developments into integrated scenarios of future developments as mentioned earlier.

Dutch land-use modelling research is highly valued internationally (Timmermans et al., 2007; Pontius et al., 2008). The well-known CLUE model from Wageningen University has mainly been applied in a wide range of foreign countries at local, national and supranational scale levels (e.g. de Koning et al., 1998; Verburg and Overmars, 2007). The Land Use Scanner model, developed by a large group of Dutch research institutes, has been applied in many Dutch policy-related research projects (Dekkers and Koomen, 2007; Koomen et al., 2005; Scholten et al., 1999; Schotten et al., 2001b). Furthermore it holds a central position in Dutch climate adaptation research, where it is used to simulate future land-use patterns and integrate sector-specific adaptation measures for urban, natural and agricultural functions (Koomen et al., 2008). Apart from these Dutch applications, the model has also been applied in several European countries (Hartje et al., 2005; Schotten et al., 2001a)8. A seriously revised version of the model became available in 2005 and offers the possibility to use a grid of 100x100 metres, covering the terrestrial Netherlands in about 3.3 million cells. This resolution comes close to the size of actual building blocks and allows the use of homogenous cells that only describe one dominant land-use per cell.

Knowledge gaps

On the basis of our review we encounter knowledge gaps dealing with how to incorporate anticipated climate changes in current calibration efforts that typically use historic data? Furthermore, research is lacking about the dynamic interaction of land-use change processes and transport developments in current land-use models. This could be useful to study, for example, the impact of strongly increased fuel prices on land-use patterns. Another important question is how socio-economic processes, such as urbanisation and agricultural developments and physical processes, and spontaneous reforestation or environmental degradation, can be successfully incorporated into a single modelling framework? Finally, including water as a land-use function - and as a necessity or constraint for certain activities - could improve the usefulness of land-use models to assess the effects of climate change.

[8] A full account of the original model is provided elsewhere (Hilferink and Rietveld, 1999). For an extensive overview of all publications related to the Land Use Scanner the reader is referred to www.lumos.info and www.feweb.vu.nl/gis.

4. Formulation of Research Themes

Now that the possible effect of climate change on several land-use activities and the existing gaps in knowledge as well as useful tools for spatial economic analysis have been described, we can formulate relevant research themes. Firstly, the integrated themes are described, then research themes related to the separate land-use activities, and finally, themes related to the research tools.

4.1 Integrated themes

Multifunctional land-use
Adaptation to climate may require a combination of measures and therefore a combination of different land-use types. Especially in cities and along rivers functions could be combined, but also protection against the sea could come together with, for example, tourism. Based on the discussion in the preceding sections we formulate the following research questions.

- *The potential of multifunctional land use in cities to cope with climate change*. What are, for example, the benefits of water and urban greenery to simultaneously address climate-related heat and water storage problems, while also providing urban amenities for residents and visitors? What are the synergies and spill-over effects of multifunctional land-use?
- *The potential of combing flood protection with other activities*. What are the possibilities of multifunctional land-use for both flood protection and other land-use activities such as tourism or residential activities?

Dealing with uncertainties in spatial economic research
One of the most important issues in adaptation to climate change is how to deal with uncertainties. Uncertainties of the level and range of effects that could be caused by climate change make it difficult to assess impacts on society from a spatial economic point of view. This leads to the general question in what ways the uncertainties about climate change and its costs and benefits affect (spatial) adaptation strategies? More in particular the following questions can be formulated:

- *Dealing with uncertainty on climate change as a basis for policy making*. Climate change scenarios are developed to describe possible climate futures without indicating the probabilities. Decision-making related to climate change is usually based on extreme cases (in the case of water: maximum sea level rise or normative discharge has to be considered). Reinforcing the link between the two is recommended in order to improve the way uncertainty can be taken into account.
- *Scenario analysis and adaptive policy making*. Given the lack of knowledge on long term developments, adaptive policy making methods are required that imply a stage-wise adaptation to changing circumstances and long-term expectations.
- *How to deal with uncertainty in cost-benefit analysis* and what is the potential of option value approaches to make the multistage character of adaptation approaches more explicit?
- How can we *incorporate risks and uncertainties* due to climate change *in current land-use models*?

Integration of physical and socio-economic developments in spatial economic research
When aiming to analyse the socio-economic effects of climate change both developments in climate change as well as in the economic situation need to be taken into account. However, economic changes develop faster than climate change. And, perhaps even more importantly, future economic developments will affect climate change; this means that there are interactions and interdependencies between the two developments which need to be taken into account although this is very complex.

- *Integration of climate and socio-economic scenarios*. Climate scenarios and socio-economic scenarios typically differ in terms of time scope and level of detail, how could they be integrated?
- *Linking of land-use change models to long-run socio-economic scenarios*. Most land-use models are based in either social or physical processes. Any truly integrated model of land-use change that can deal with climate change should be able to capture socio-economic processes such as urbanisation and agricultural developments and physical processes such as spontaneous reforestation or environmental degradation. The challenge here is that these processes typically follow a different logic and take place on a different time scale.

4.2 Land-use specific themes

Agriculture
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*. 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 in the Netherlands for different kinds of production, e.g. aquatic agriculture? And how could changes in farm management, such as crop rotation schemes, benefit farmers in the different regions of the Netherlands?
- *The demand for freshwater in the agricultural sector.* Thus far, freshwater is available for free to the agricultural sector in the Netherlands. But when the supply of fresh water leads to high costs (cf. the policies for lake IJssel) 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.
- *Coping 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?

Nature
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.

- *Ecosystem services*. What are the benefits of ecosystem services such as (wet) nature areas preventing a lowering of the soil and the emission of greenhouse gas from peat lands?
- *Biodiversity and invasive species*. 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?

Tourism
In the Alpine and Mediterranean regions climate change will probably have a negative effect on the tourism sector. However, in the Netherlands higher temperatures and less rainfall during the summer months could result in an increasing number of tourists.

- *Behavioural changes in tourism and recreation.* What are the economic and spatial effects in Europe and in the Netherlands of tourists changing their behaviour due to climate change by choosing other regions in which to spend their holidays or by using other means of transport? What could be effective policy measures?
- *Future demand of space for tourism in the Netherlands*. What will be the future demand for space for recreational and tourism purposes in various types of areas in the Netherlands, such as coastal and forest areas, cities and watersport areas, taking into account the anticipated climate change?

Urban areas

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.

- What are the regional implications of climate change (especially the frequency of hot days) on *health issues and labour productivity* and what could be effective measures to cope with this?
- *Value of greenery in urban areas*. What are the costs and benefits of more greenery in urban areas in order to deal with the urban heat island effect, as well as with extreme precipitation taking into account the extra amenities for residents and visitors?

Transport

For transport activities the most important climate changes will be the increase in extreme weather conditions, leading to an increase in infrastructure and transport disruptions. In addition, low and high water levels can affect inland waterway transport and changes in wind patterns may affect air transport.

- *Climate change implications for the competitive position of water transport*. What are the implications of increasing costs due to low and high water levels on water transport, and what are the consequences for land-use of port activities and main sectors relying on water transport?
- *Robust road and rail networks in the context of climate change.* Transport systems are vulnerable in the case of disasters. Therefore issues of robustness of network designs to maintain the functioning of transport systems in the case of disasters have to be explored.
- *Adverse weather and travel time reliability.* The relation between adverse weather and travel time reliability has largely been unexplored. Nevertheless, in addition to weather-related changes in mean travel time, changes in travel reliability represent a substantial economic value. Therefore the effects of adverse and extreme weather on travel reliability and the associated economic costs deserve further scrutiny.
- *Extreme weather conditions, transport costs and choice of mode of transport.* An increase in the frequency and intensity of extreme weather conditions due to climate change may cause substantial increases in infrastructure disruptions and associated transport costs. Analysis into these costs for various modes of transport is therefore warranted, and may shed light on changes in the competitive positions of these modes of transport, both passenger and freight.
- *Climate change, air transport and airport planning.* If climate change adds to the uncertainty about future wind directions then it implies (for a country like the Netherlands where wind is an important issue in airport operations) that there may be a need for additional spatial reservations to keep options open for future expansion plans.

Water

Water is a very important issue when discussing the issues of climate change 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. The following strategic research questions have been identified:

- *Reactions of households to changes in water-related risks.* The flood risks in the Netherlands are rather low so their effects cannot be easily determined. More in-depth analysis is needed to determine to what extent flood risks have impact. This would be a major input to an appropriate analysis of the benefits of safety policies.
- *Reactions of the business sector 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?
- *Spatial reservations in the context of policies to reduce the risk of flood.* What are the actual costs of reserving space for flood risk measures or for water storage? Would it be possible and preferable to give designated areas another function temporarily?
- *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?

4.3. Spatial economic analysis

Performing spatial economic analyses of adaptation to climate change is highly complex as it involves a variety of different processes, different scales and different time frames. The following strategic research questions are applicable.

Scenarios

- *Scenario analysis and local conditions*. Adaptation measures in KvK are considered at the regional and local level. Scenarios are typically developed at the national and international level. This implies that there is a need for tools to translate national scenarios into regional and local ones, including scenarios of future land-use, related to ‘spatial reservation strategies’.

Evaluation

- *Underdeveloped elements in SCBA in the context of climate change***.** To be able to estimate the efficiency of adaptation measures, especially those related to water management, more research is needed into the costs and benefits of relevant issues. These are for example: direct and indirect costs of (flood) disasters, value of statistical life in flood contexts, costs of non-fatal accidents, group risk, landscape and cultural heritage values, loss of reputation due to high-risk status, societal disruption, etc.

Land-use modelling

While current land-use models, such as the Land Use Scanner are helpful in climate adaptation research, they can be improved in several ways.

- *Incorporating effects of adaptive policies in models for land-use change***.** In land-use models until now the effects of possible adaptive measures have not been taken into account. However, showing the effect of, for example, spatial reservation strategies, changes in risk levels, creation of water buffers and multifunctional land is very useful.
- *The calibration of most land-use models needs refining*. Enhancements are especially needed in the way anticipated climate-induced changes can be incorporated in current modelling frameworks.
- *Introducing a dynamic interaction of land-use change processes and transport developments.* Incorporation of this interaction in current spatially explicit land-use models that simulate changes in urban, agricultural and natural land uses would strongly improve their performance. Combining these two approaches would, for example, allow an assessment of the impact of strongly increased fuel prices on land-use patterns.
- *Introducing water as a land-use function and as a necessity or constraint to spatial activities.* By including water more convincingly in land-use models, the importance of water for (economic) development and adaptation to climate change can be better assessed.

5. Conclusions

When studying the existing literature about adaptation strategies from a spatial economic point of view it appears that adaptation is not a widely covered subject in the principal journals. Physical dimensions are not entirely ignored, but dimensions such as knowledge, human capital, and institutions receive much more attention. Therefore we have broadened our search towards contributions that still have a clear spatial economic orientation, but that have been published in journals with a more multidisciplinary orientation. Taking Table 1 as a point of departure, it appears that not all subjects are evenly covered. Much is written about the possible effects of climate change on agriculture, nature or transport in general but not so much about specific local effects or about possible adaptation strategies. Furthermore, it appears that literature about the effect on freshwater supply, on (large) business parks or about residential activities outside cities is strongly underdeveloped.
In addition, when looking at tools for spatial economic analysis, important challenges are to develop approaches to deal with uncertainty and different spatial scales or timeframes.
The strategic research themes formulated in Chapter 4 promises to lead to a research programme that provides an attractive combination of fundamental research work and a high strategic relevance for policies aiming at developing a climate-proof society in a cost-effective way.

Acknowledgements
We would like to acknowledge those persons that attended the expert meeting who contributed to this report by their critical and useful comments. In particular we would like to thank: Peter Driessen, Ekko van Ierland, Judith Borsboom, Rob Zwart, Pieter Valkering, Kay van der Zand, Katrien Termeer, Kees van Deelen, Marianne Kuijpers, Nico Lansman and Rosa Uylenburg.

Summary

Society will be affected by climate change in many different ways, both from an economic and a spatial perspective. However, large uncertainties and large variations in possible effects make it difficult to obtain a clear view on possible developments and hamper a sustainable and efficient response.
In this study, an inventory is made of the contributions to the scientific literature that addresses adaptation to climate change from a spatial economic perspective. We take land-use as a point of departure since it is an important factor in spatial economics, and it also plays a key role in the mechanisms linking economic activities and physical conditions. We distinguish between agriculture, nature, tourism, urban and transport activities and water (safety). Although, most of these activities contribute to climate change as well, we mainly focus on the effect climate change has on them, as well as on possible adaptation strategies both at the global level and the national level. Furthermore, an inventory is made of useful (analytical) tools for assessing the impact of climate change on the spatial economy, such as scenario analysis, cost-benefit analysis, and land-use modelling. Finally, a set of relevant (future) research themes has been formulated.
Relevant research themes that we describe are first of all related to multifunctionality: what is the potential of multifunctional land-use in cities to cope with climate change and what is the potential of combining flood protection with other activities? A second research theme is dealing with uncertainties in spatial economic research. More specifically, important questions are how to deal with uncertainty in cost-benefit analysis and the incorporation of risks and uncertainties, as well as how to deal with uncertainty on climate change as a basis for policy making. A third research challenge is the integration of physical and socio-economic developments in spatial economic research, such as the integration of climate and socio-economic scenarios and the linking of land-use change models to long-run socio economic scenarios. Furthermore, land-use specific research themes and methodological research themes have been addressed.

Samenvatting

Onze samenleving zal op verschillende manier beïnvloed worden door klimaat veranderingen, zowel vanuit een economisch als een ruimtelijk perspectief. Vooral de grote onzekerheden en verschillende mogelijke effecten maken het lastig om een duidelijk overzicht te krijgen van toekomstige ontwikkelingen en belemmeren een duurzame en efficiënte reactie.
In deze studie is een inventarisatie gemaakt van de bijdragen aan de wetenschappelijke literatuur die betrekking hebben op adaptatie, oftewel aanpassingen, aan klimaatverandering vanuit een ruimtelijk economisch oogpunt. Omdat landgebruik het punt is waar economische activiteiten en fysische condities elkaar raken, kijken we per gebruiksvorm naar wat in de literatuur geschreven is over algemene klimaatontwikkelingen, specifiek Nederlandse ontwikkelingen, mogelijke adaptatie strategieën en kennisleemtes. We onderscheiden: landbouw, natuur, toerisme, stedelijke en transport activiteiten en

water(veiligheid). Verder is er gekeken naar mogelijke adequate onderzoeksinstrumenten om het effect van klimaatveranderingen op ruimtelijke economische thema's te analyseren en evalueren, zoals scenario analyse, kosten-batenanalyse en landgebruikmodellering.

Aan de hand van de inventarisaties zijn relevante onderzoeksthema's geformuleerd. Allereerst het thema multifunctionaliteit: wat zijn bijvoorbeeld de mogelijkheden van multifunctioneel ruimtegebruik in steden om de negatieve effecten van klimaatverandering te compenseren en hoe kan bescherming tegen overstroming gecombineerd worden met andere functies? Een tweede thema is onzekerheid: hoe kan onzekerheid en de risico's van onzekerheden meegenomen worden in kosten-batenanalyses en hoe kunnen beleidsmakers omgaan met onzekerheid? Een derde thema is de integratie van fysische en sociaaleconomische ontwikkelingen in ruimtelijk economisch onderzoek, zoals de integratie van klimaat scenario's met sociaaleconomische scenario's en het de integratie van landgebruikmodellering in lange termijn sociaaleconomische scenario's. Tenslotte is er nog een aantal onderzoeksthema's per landgebruikvorm gedefinieerd.

References

Aerts, J. (2008). Klimaatbestendig bouwen op een Vinexterp. De Water, april 2008, pp. 7-8.

Al Hassan, Y. & D.J. Barker (1999). The Impact of Unseasonable or Extreme Weather on Traffic Activity within Lothian Region, Scotland. Journal of Transport Geography 7, pp. 209–213.

Alcamo, J., R., Leemans & E., Kreileman (1998). Global Change Scenarios of the 21st Century. Results from the IMAGE 2.1 Model. Elsevier, Amsterdam.

Amelung, B., D. Viner, (2006). Mediterranean Tourism: Explaining the Future with the Tourism Climatic Index. Journal of Sustainable Tourism 14, pp. 349–366.

Andrey, J.C., B. Mills, M. Leahy, & J. Suggett (2003). Weather as a Chronic Hazard for Road Transportation in Canadian Cities. Natural Hazards 28, pp. 319–343.

Ar4 (2007). The Working Group II contribution to the IPCC Fourth Assessment Report. http://www.ipcc-wg2.com

AVV (2006). Economische Waardering van Mobiliteitseffecten van een Dijkdoorbraak [Economic Valuation of Mobility Effects of a Flood]. AVV, Ministry of Transport, Public Works and Water Management, Rotterdam.

Becken S. & J.E. Hay (2007). Tourism and Climate Change: Risks and Opportunities. Multilingual Matters,.

Bergh, J.C.J.M. van den (2004). Optimal climate policy is a utopia: from quantitative to qualitative cost-benefit analysis. Ecological Economics, Vol. 48 (4), pp. 385-393.

Berrittella, M., A. Bigano, R. Roson, & R. S.J. Tol (2006). A general equilibrium analysis of climate change impacts on tourism. Tourism Management, Vol. 27(5), pp. 913-924.

Blaeij, A. de, R. J. G. M. Florax, P. Rietveld & E. Verhoef (2003). The value of statistical life in road safety: a meta-analysis. Accident Analysis & Prevention, Vol. 35 (6), pp. 973-986.

Bleda, M. & S. Shackley (2008). The dynamics of belief in climate change and its risks in business organizations. Ecological Economics, Vol. 66(2-3), pp. 517-532.

Borsboom-van Beurden, J.A.M., A. Bakema, & H.Tijbosch (2007). A land-use modelling system for environmental impact assessment; Recent applications of the LUMOS toolbox. Chapter 16. In: E. Koomen, J. Stillwell, A. Bakema, and H.J. Scholten (eds.), Modelling land-use change; progress and applications. Springer, Dordrecht, pp. 281-296.

Borsboom-van Beurden, J.A.M., A.A. Bouwman, & W.T. Boersma (2008). Spatial elaboration of long-term scenarios. Future land use in the Netherlands. Environment and Planning B: Planning and Design submitted.

Brouwer, R. & R. van Ek (2004). Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. Ecological Economics, Vol. 50 (1-2), pp. 1-21.

Changnon, S.A. (1996). Effects of Summer Precipitation on Urban Transportation. Climatic Change 32, pp. 481–494.

Chen Y. & N.H. Wong (2006).Thermal benefits of city parks. Energy and Buildings, Vol. 38 (2), pp. 105-120.

Chloupek, O., P. Hrstkova & P. Schweigert (2004). Yield and its stability, crop diversity, adaptability and response to climate change, weather and fertilisation over 75 years in the Czech Republic in comparison to some European countries. Field Crops Research 85, pp. 167-190.

Chornesky, E.A., A.M. Bartuska, G.H. Aplet, K.O. Britton, J. Cummings-Carlson, F.W. Davis, J. Eskow; D.R. Gordon, K.W. Gottschalk & R.A. Haack (2005). Science priorities for reducing the threat of invasive species to sustainable forestry. BioScience Vol.55 (4), pp. 335-348.

Chung, E., O. Ohtani, H.Warita, M. Kuwahara & H. Morita (2005). Effect of Rain on Travel Demand and Traffic Accidents. Intelligent Transportation Systems, 2005. Proceedings. 2005 IEEE, pp. 1080 – 1083.

Commissie MER (2002). Geactualiseerde notitie over multicriteria-analyse in Milieueffectrapportage. Commissie voor de milieueffectrapportage, Utrecht.

CPB (2002). Gevolgen van Uitbreiding Schiphol [Consequences of Extension of Schiphol Airport]. CPB, Den Haag.

Dale, V.H. (1997). The relationship between land-use change and climate change. Ecological Applications Vol. 7(3), pp. 753-769.

Dantzig, D. van (1956). Economic decision problems for flood prevention, Econometrica Vol 24(3) pp. 276-287.

Dasgupta, S., B. Laplante C., Meisner, D. Wheeler & J. Yan (2007). The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis. Policy Research Working Paper WPS 4136. World Bank, Washington, D.C.

Defra (2004). Making space for water, Developing a New Government Strategy for Flood and Coastal Erosion Risk Management in England. Department for Environment, Food and Rural Affairs, London.

Dekkers, J.E.C. & E. Koomen (2007). Land-use simulation for water management: application of the Land Use Scanner model in two large-scale scenario-studies. Chapter 20. In: E. Koomen, J. Stillwell, A. Bakema and H.J. Scholten (eds.), Modelling land-use change; progress and applications. Springer, Dordrecht, pp. 355-373.

Deltacommissie (2008). Samen werken met water Een land dat leeft, bouwt aan zijn toekomst. Bevindingen van de Deltacommissie 2008.

Döpp, S & R. Albers (2008). Klimaatverandering in Nederland: Uitdagingen voor een leefbare stad. TNO, Utrecht.

Drunen, M. van (2006). Naar een klimaatbestendig Nederland. Samenvatting routeplanner. Klimaat voor Ruimte

Drunen, M. van, R. Lasage & S. Brinkman (2007). Klimaatverandering in stedelijke gebieden. Een inventarisatie van bestaande kennis en openstaande kennisvragen over effect en adaptatiemogelijkheden. Nationaal Onderzoeksprogramma Klimaat voor Ruimte.

Duinmeijer, A.G.P. & R. Bouwknegt (2004). Betrouwbaarheid Railinfrastructuur 2003 [Reliability Rail Infrastructure 2003]. Prorail, Utrecht.

Dupuit, J. (1844). On the measurement of Utility of Public Works. In: D. Murphy (ed.), Transport, Penguin, London.

Easterling, W.E., P.K. Aggarwal, P. Batima, K.M. Brander, L. Erda, S.M Howden, A. Kirilenko, J. Morton , J.-F. Soussana, J. Schmidhuber & F.N. Tubiello (2007). Food, Fibre and Forest Products. In: IPCC (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, pp. 273–313.

EC (2006). Biofuels in the European Union. A VISION FOR 2030 AND BEYOND. Final report of the Biofuels Research Advisory Council. European Commission Directorate-General for Research. Report EUR 22066

Eickhout, B., H. Van Meijl, A.Tabeau, & T.van Rheenen (2007). Economic and ecological consequences of four European land use scenarios. Land Use Policy, Vol. 24, pp. 562-575.

Eijgenraam, C. (2006). Optimal safety standards for dike-ring areas. CPB Discussion Paper 62.

Eisenberg, D. & K.A. Warner (2005). Effects of Snowfalls on Motor Vehicle Collisions, Injuries, and Fatalities. American Journal of Public Health Vol. 95, pp. 120–124.

Elsasser, H. & R. Bürki (2002). Climate Change as a Threat to Tourism in the Alps. Climate Research 20, pp. 253–257.

Ewert, F., M.D.A. Rounsevell, I. Reginster, M.J. Metzeger, & R. Leemans (2005). Future scenarios of European agricultural land use. Estimating changes in crop productivity. Agriculture, Ecocsystems and Environment Vol. 107, pp. 101-116.

Fischer, G., K. Frohberg, M.L. Parry & C. Rosenzweig (1994). Climate Change and World Food Supply, Demand and Trade. Global Environmental Change 4, pp. 7–23.

Fischer, G., M. Shah & H. van Velthuizen (2002). Climate Change and Agricultural Vulnerability. International Institute for Applied Systems Analysis (IIASA), Vienna, Austria.

Flörke, M & J. Alcamo (2005). European outlook on water use. Prepared for the European Environment Agency. Center for Environmental Systems Research, University of Kassel.

Gelder, P.H.A.J.M. van (1999). Risks and safety of flood protection structures in the Netherlands, Proceedings of the Participation of Young Scientists in the Forum Engelberg 1999 on Risk and Safety of Technical Systems - in View of Profound Changes, pp.55-60

Gössling, S., P. Peeters & D. Scott (2008). Consequences of climate policy for international tourist arrivals in developing countries. Third World Quarterly, Vol. 29 (5), pp. 873 - 901.

Groot de R.S., E.C. van Ierland, P.J. Kuikman, E.E.M. Nillesen , M. Platteeuw, V.C. Tassone, A.J.A. Verhagen, & S. Verzandvoort-van Dijck(2006). Climate Adaptation in the Netherlands. Netherlands Environmental Assessment Agency, Bilthoven.

Hartje, V., A. Klaphake, M. Grossman, K. Mutafoglu, J. Borgwardt, J. Blazejczak, M. Gornig, T. Ansman, E. Koomen & J.E.C. Dekkers (2005). Regional Projection of Water Demand and Nutrient Emissions - The GLOWA-Elbe approach. Poster presented at the Statuskonferenz Glowa-Elbe II, Köln May 18-19, 2005.

Hilferink, M. & P. Rietveld (1999). Land Use Scanner: An integrated GIS based model for long term projections of land use in urban and rural areas. Journal of Geographic Systems, Vol. 1 (2), pp. 155-177.

Hranac, R., E. Sterzin, D. Krechmer, H. Rakha, M. Farzaneh (2006). Empirical Studies on Traffic Flow in Inclement Weather, Publication No. FHWA-HOP-07-073, Federal Highway Administration, Washington, D.C.

ICF (2008). The Potential Impacts of Global Sea Level Rise on Transportation Infrastructure. http://climate.dot.gov/publications/potential_impacts_of_global_sea_level_rise/. ICF International, Fairfax, Virginia.

Ierland, E.C. van, R.S. de Groot, P.J. Kuikman, P. Martens, B. Amelung, N. Daan, M. Huijnen, K. Kramer, J. Szönyi, J.A. Veraart, A. Verhagen, A. van Vliet, P.E.V. van Walsum & E. Westein (2001), Integrated assessment of vulnerability to climate change and adaptation options in the Netherlands, NRP-CC.

Ierland, E.C. van, K. de Bruin, R.B. Dellink, A.J.W. Ruijs, L. Bolwidt, A. van Buuren, J. Graveland, R.S. de Groot, P.J. Kuikman, E.E.M. Nillesen, M. Platteeuw, S. Reinhard, V.C. Tassone, A. Verhagen, R.P. Roetter, S.J.E. Verzandvoort-van Dijck (2007). Routeplanner naar een klimaatbestendig Nederland: Adaptiestrategiën: 3: A qualitative assessment of climate adaptation options and some estimates of adaptation costs. Klimaat voor Ruimte, Wageningen, p. 145.

IPCC (2007). Climate Change 2007 - Impacts, Adaptation and Vulnerability; Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Parry, M., Canziano, O., Palutikof, J., Van der Linden, P. and Hanson, C. (eds.). Cambridge University Press, Cambridge.

IPPC (2000). Emissions scenarios, summary for Policymakers. A Special Report of IPCC Working Group III. IPCC, Geneva, Switzerland

Jacob, K.H., N. Edelblum & J. Arnold (2001). Infrastructure. In: C. Rosenzweig and W.D. Solecki, (Eds.), Climate Change and a Global City: The Potential Consequences of Climate Variability and Change - Metro East Coast, Columbia Earth Institute, New York, pp. 47–65.

Jonkeren, O., B. Jourquin & P. Rietveld (2008). Modal Split Effects of Climate Change: A Study to the Effect of Low Water Levels on the Competitive Position of Inland Waterway Transport in the River Rhine Area. Department of Spatial Economics, Vrije Universiteit, Amsterdam.

Jonkeren, O., P. Rietveld, J. van Ommeren (2007). Climate change and inland waterway transport: Welfare effects of low water levels on the river Rhine, Journal of Transport Economics and Policy, Vol. 41, pp. 387-411.

Kafalenos, R.S. & K.J. Leonard (2008). What are the Implications of Climate Change and Variability for Gulf Coast Transportation? In: M.J. Savonis, V.R. Burkett and J.R. Potter (Eds.), Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I, Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Department of Transportation, Washington, DC, USA.

Karacavus, B. & A. Can (2009). Thermal and economical analysis of an underground seasonal storage heating system in Thrace. Energy and Buildings, Vol. 41 (1), pp. 1-10.

Keay, K., & I. Simmonds (2005). The Association of Rainfall and other Weather Variables with Road Traffic Volume in Melbourne, Australia. Accident Analysis and Prevention 37, pp. 109–124.

Kind, J. (2008). Kengetallen Kosten-batenanalyse Waterveiligheid 21e eeuw. RWS/ Waterdienst.

KNMI (2006). Klimaat in de 21e eeuw, vier scenario’s voor Nederland. Bilthoven: KNMI 2006.

Koetse, M.J. & P. Rietveld (2007). Gevolgen van Klimaatverandering voor de Transportsector: Een Overzicht van de Literatuur. Tijdschrift Vervoerswetenschap 43, pp. 4–14.

Koetse, M.J., & P. Rietveld (2008). The Impact of Climate Change and Adverse Weather on Transport: An Overview of Empirical Findings. Department of Spatial Economics, VU University, Amsterdam.

Kok, M.T.J., G.J. Heij, A. Verhagen & C.A. Rovers (2001). Klimaatverandering, een aanhoudende zorg. Eindrapportage tweede fase Nationaal Onderzoek Programma Mondiale Luchtverontreiniging en Klimaatverandering (NOP-II), 1995-2001. NOP rapport 410 200 113, 176 pp.

Koomen, E., T. Kuhlman, J. Groen & AA. Bouwman (2005). Simulating the future of agricultural land use in the Netherlands. Tijdschrift voor Economische en Sociale Geografie [Journal of Economic and Social Geography], Vol. 96(2), pp. 218-224.

Koomen, E., J. Stillwell, A. Bakema & H.J. Scholten (2007). Modelling land-use change; progress and applications. Geojournal library, Vol. 90. Springer, Dordrecht.

Koomen, E., W. Loonen & M. Hilferink (2008). Climate-change adaptations in land-use planning; a scenario-based approach. In: L. Bernard, A. Friis-Christensen and H. Pundt (eds.), The European Information Society; Taking Geoinformation Science One Step Further. Springer, Berlin, pp. 261-282.

Koning, G.H.J. de, A.Veldkamp, P.H.Verburg, K.Kok & A.R.Bergsma. (1998) CLUE: A tool for spatially explicit and scale sensitive exploration of land use changes. In: Stoorvogel, J.J., J.Bouma and W.T.Bowen (eds.) Quantitative Approaches in Systems Analysis no.16. Lima, Peru. Information technology as a tool to assess land use options in space and time. Proceedings of an international workshop.

Kron, W. (2006). Dealing with Flood Risk. *Stockholm Water Front*, Vol. 3, pp. 16-18

Kulesa, G. (2002). Weather and Aviation: How Does Weather Affect the Safety and Operations of Airports and Aviation, and How Does FAA Work to Manage Weather-Related Effects? The Potential Impacts of

Climate Change on Transportation Workshop, October 1-2, 2002, DOT Center for Climate Change and Environmental Forecasting.

Leemans, R. & B. Eickhout (2004). Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. Global environmental change, Vol. 14, pp. 219-228.

Leeuwen, B.H. van (2007). Natuurbeleid wordt doelloos. De Levende Natuur Vol. 108 (1), pp. 100-11

Leeuwen, E.S., van & P. Nijkamp (2007). Foundations of Scenario Design. Report for AG2020: Foresight Analysis for World Agricultural Markets (2020) in Europe, Contract no.: 44280-AG2020.

Leung, J. & J. Guria (2006). Value of statistical life: Adults versus children. Accident Analysis & Prevention, Vol. 38(6), pp. 1208-1217

Lind, N. (2007). Discounting risks in the far future. Reliability Engineering & System Safety, Vol. 92 (10), pp. 1328-1332.

Lind, N., M. Pandey & J. Nathwani (2008). Assessing and affording the control of flood risk. Structural Safety, In Press, Corrected Proof, Available online 3 August 2008.

Lise, W. & R.S.J. Tol (2002). Impact of Climate on Tourism Demand. Climatic Change Vol. 55, pp. 429–449.

Ma, T., A. Grubler & Y. Nakamori (2009). Modeling technology adoptions for sustainable development under increasing returns, uncertainty, and heterogeneous agents. European Journal of Operational Research, Vol. 195 (1), pp. 296-306.

Manen, van, S.E. & M. Brinkhuis (2005). Quantitative flood risk assessment for Polders. Reliability Engineering & System Safety, Vol. 90 (2-3), pp. 229-237.

Meulen, M.J. van der, A.J.F. van der Spek, G. de Lange, S.H.L.L. Gruijters, S.F. van Gessel, B. Nguyen, D. Maljers, J. Schokker, J.P.M. Mulder & R.A.A. van der Krogt (2007). Regional Sediment Deficits in the Dutch Lowlands: Implications for Long- Term Land-Use Options. Journal of Soils Sediments Vol. 7(1), pp. 9-16.

Millerd, F. (2005). The Economic Impact of Climate Change on Canadian Commercial Navigation on the Great Lakes. Canadian Water Resources Journal, Vol. 30, pp. 269–280.

Min LNV (2008). Feiten en cijfers van de Nederlandse Agrosector 2008. Ministry of Agriculture Nature and Food quality, The Hague.

Ministry of Transport Public Works and Water Management (2006). Spatial Planning Key Decision ‘Room for the River’; Investing in the safety and vitality of the Dutch river basin region. Ministry of Transport Public Works and Water Management, The Hague.
MNP, 2005. Effecten van klimaatverandering in Nederland. Milieu en Natuurplanbureau, Bilthoven. MNP-rapportnummer: 773001034, 111 pp.

MNP (2005b). Nederland Later. Tweede Duurzaamheidsverkenning, deel Fysieke leefomgeving Nederland. Milieu en natuurplanbureau, Bilthoven.

Mooij, R. de, & P. Tang (2003). Four Futures of Europe, nr. 49. Netherlands Bureau for Economic Policy Analysis, Den Haag, the Netherlands.

Neumayer, E. (2007). A missed opportunity: The Stern Review on climate change fails to tackle the issue of non-substitutable loss of natural capital. Global Environmental Change, Vol. 17 (3-4), pp. 297-301.

Nicholls, S. & B.Amelung (2008). Climate Change and Tourism in Northwestern Europe: Impacts and Adaptation. Tourism Analysis 13.

Nijkamp, P., S.A. Rienstra & J.Vleugel (1998). Transportation Planning and the Future. Wiley, Chichester, England.

Nordhaus (2007). A review of the Stern Review on the economics of climate change. Journal of Economic Literature 45 (3), pp. 686–702.

OECD (2007). Ranking of the world's cities most exposed to coastal flooding today and in the future.

Olesen, J.E. & M. Bindi, M (2002). Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy, Vol. 16, pp. 239-262.

Olesen, J.E., S. Yang, H. Christensen, M. Bindi & L. Orioli (2008). Climate change impacts on agricultural production. First report for AG2020: Foresight Analysis for World Agricultural Markets (2020) in Europe, Contract no.: 44280-AG2020.

Olsen, J.R., L.J. Zepp & C.A. Dager (2005). Climate Impacts on Inland Navigation, in: World Water and Environmental Resources Congress 2005, May 15–19, 2005, Anchorage, Alaska, USA.

Ooststroom, H. van, J.A. Annema, & J. Kolkman (2008). Effecten van Klimaatverandering op Verkeer en Vervoer: Implicaties voor Beleid. Kennisinstituut Mobiliteitsbeleid, Den Haag.

OTA (1993). Harmful Non-Indigenous Species in the United States, Office of Technology Assessment, United States Congress, Washington DC.

Paelinck, J.H. & P. Nijkamp (1975). Operational theory and method in regional economics. Saxon House, Westmead.

Parry, M.L. (2000a). Assessment of Potential Effects and Adaptations for Climate Change in Europe: The Europe ACACIA Project. Jackson Environmental Institute, University of East Anglia, Norwich, UK.

Parry, M.L. (2000b). Scenarios for climate impact and adaptation assessment. Geographical Environmental Change, Vol. 12, pp. 149-153.

Pfafferott, J.U., S. Herkel, D. E. Kalz & A. Zeuschner (2007).Comparison of low-energy office buildings in summer using different thermal comfort criteria. Energy and Buildings, Vol. 39(7), pp. 750-757.

Pielke Jr., R. (2007). Mistreatment of the economic impacts of extreme events in the Stern Review Report on the Economics of Climate Change. Global Environmental Change, Vol. 17 (3-4), pp. 302-310.

Pimentel, D., R. Zuniga & D. Morrison (2005). Integrating Ecology and Economics in Control Bioinvasions. Ecological Economics, Vol.52 (3), pp. 273-288.

Pontius Jr., R.G., W. Boersma, J.-C. Castella, K. Clarke, T. De Nijs, C. Dietzel, Z. Duan, E. Fotsing, N. Goldstein, K. Kok, E. Koomen, C.D. Lippitt, W. McConnell, B.C. Pijanowski, S. PithadiaA. Mohd Sood, S. Sweeney, T.N. Trung, T.A. Veldkamp & P.H. Verburg (2008). Comparing the input, output, and validation maps for several models of land change. Annals of Regional Science , Vol. 42 (1), pp. 11-37.

Posthumus, H., C.J.M. Hewett, J. Morris & P.F. Quinn (2008). Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. Agricultural Water Management, Vol. 95 (7), pp. 787-798.

Rajagopalan P., H. Wong Nyuk, D. Cheong Kok Wai (2008). Microclimatic modeling of the urban thermal environment of Singapore to mitigate urban heat island. Solar Energy, Vol. 82 (8), pp. 727-745.

Reijs, Th. A. M. (2008). Eilanden voor de kust van Nederland, Pre-feasibility verkenning. TNO, Delft.

Reilly, J., Schimmelpfennig, D., 1999. Agricultural impact assessment, vulnerability, and the scope for adaptation. Climate Change, Vol. 43, pp. 745-788.

Ros, J., D. Nagelhout & J. Montfoort (2009). New environmental policy for system innovation: Casus alternatives for fossil motor fuels. Applied Energy, Vol. 86(2), pp. 243-250.

Sabir, M., J .van Ommeren, M.J. Koetse & P. Rietveld (2008). Welfare Effects of Adverse Weather Through Speed Changes in Car Commuting Trips. Forthcoming as Tinbergen Institute Discussion Paper. VU University, Amsterdam.

Safecoast (2008). Coastal flood risk and trends for the future in the North Sea region, synthesis report. Safecoast project team. The Hague, pp. 136

Scholten, H.J., R.J. van de Velde, P. Rietveld & M. Hilferink (1999). Spatial information infrastructure for scenario planning: the development of a Land Use Planner for Holland. In: J. Stillwell, S. Geertman and S. Openshaw (eds.), Geographical Information and Planning. Springer-Verlag, Berlin/Heidelberg/New York, pp. 112-134.

Schotten, C.G.J., C.Heunks, A.J.Wagtendonk, J.J.G.Buurman, C.J.de Zeeuw, H.Kramer and W.T.Boersma (2001a). Simulating Europe in the 21th century. NRSP-2 report 00-22 . BCRS, Delft.

Schotten, C.G.J., R. Goetgeluk, M. Hilferink, P. Rietveld and H.J. Scholten (2001b). Residential construction, land use and the environment. Simulations for the Netherlands using a GIS-based land use model. Environmental modeling and assessment Vol. 6, pp. 133-143.

Scott, D., G. McBoyle, B. Mills and G. Wall (2001). Assessing the Vulnerability of the Alpine Skiing Industry in Lakelands Tourism Region of Ontario, Canada to Climate Variability and Change.

Semadeni-Davies, A., C. Hernebring, G. Svensson & L.G. Gustafsson (2008). The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. Journal of Hydrology, Vol. 35 (1-2), pp. 100-113.

Semenza J. C., D.l J. Wilson, J. Parra, B. D. Bontempo, M. Hart, D. J. Sailor and L. A. George (2008). Public perception and behavior change in relationship to hot weather and air pollution. Environmental Research, Vol. 107 (3), pp. 401-411.

Shankar, V.N., S. Chayanan, S. Sittikariya, M. Shyu, N.K. Juwa & J.C. Milton (2004). Marginal Impacts of Design, Traffic, Weather, and Related Interactions on Roadside Crashes. Transportation Research Record 1897, pp. 156–163.

Shankar, V.N., S. Chayanan, S. Sittikariya, M. Shyu, N.K. Juwa, & J.C. Milton (2004). Marginal Impacts of Design, Traffic, Weather, and Related Interactions on Roadside Crashes. Transportation Research Record 1897, 156–163.

Shogren, J.F. & T. Stamland (2006). Consistent estimation of the value of statistical life. Resource and Energy Economics, Vol.28 (3), pp. 262-281.

Simpson, M.C., S. Gössling, D. Scott, C.M. Hall & E. Gladin (2008). Climate Change Adaptation and Mitigation in the Tourism Sector: Frameworks, Tools and Practices.UNEP, University of Oxford, UNWTO, WMO: Paris, France.

Sonne J.K. & R.K. Viera (2000). Cool neighborhoods: the measurement of small scale heat islands. Proceedings of 2000 Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, Washington, DC.

Stern, N. (2006). Stern Review on the Economics of Climate Change, UK Government Economic Service, London (2006).

Timmermans, H., M. Batty, H. Couclelis & M. Wegener (2007). Scientific Audit Of National Land Use Models; Report and Recommendations of the Audit Committee. Netherlands Environmental Assessment Agency (MNP), Bilthoven.

TNO (2008). Economische effecten van klimaatverandering, overstroming en verzilting in scenario's, modellen en cases. TNO, Delft.

Unrau, D. & J. Andrey (2006). Driver Response to Rainfall on Urban Expressways. Transportation Research Record 1980, pp. 24–30.

Verburg, P.H. & K.P. Overmars (2007). Dynamic simulation of land-use trajectories with the CLUE-s model. Chapter 18. In: Koomen, E., Stillwell, J., Bakema, A. and Scholten, H.J. (eds.), Modelling land-use change; progress and applications. Springer, Dordrecht, pp. 321-335.

Verhoef, E.T. (1999). Externalities. In: J.C.J.M. van den Bergh (ed.), Handbook of Environmental and Resource Economics. Aldershot, Edgar Elgar, pp. 197-213.

Vreeker, R. & P. Nijkamp (2005). Multicriteria Evaluation of Transport Policies . In: D.A. Henscher and K.J. Button (eds.), *Handbook of Transport and Environment, Handbooks in Transport 4* Elsevier / Pergamon, Amsterdam.

Vreeker, R., P. Nijkamp, & G. Munda (2006). Evaluation of Sustainable Urban Development; Cost Benefit Analysis and Multicriteria Analysis. In: M. Deakin, P. Nijkamp, G. Mitchell and R. Vreeker (eds), Sustainable Urban Development Vol. 2; The Environmental Assessment Methods, Routledge.

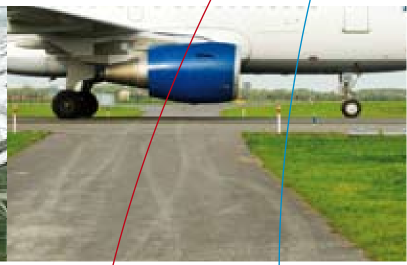
Vrijling, J.K., W. van Hengel and R.J. Houben (1998). Acceptable Risk as a basis for Design. Reliability Engineering and System Safety 59, pp. 141-150.

Watson, R.T., I.R. Noble, B. Bolin, N.H.V.D.J. Ravindranath, & D.J.E. Dokken (2000). Land Use, Land-Use Change, and Forestry. A Special Report of the Intergovernmental Panel on Climatic Change. A special report of the IPCC. Cambridge University Press, Cambridge.

Werners, S., A. Verhagen & A. Gerritsen (2004). Adaptation to climate change in the Netherlands. Dutch contribution to the review of climate change vulnerability assessments and adaptation strategies in the EEA member countries, European Environmental Agency, 20 pp.

Wesselink, A.J. (2007). Flood safety in the Netherlands: The Dutch response to Hurricane Katrina. Technology in Society, Vol. 29 (2), pp. 239-247.



To develop the scientific and applied knowledge required for climate-proofing the Netherlands and to create a sustainable knowledge infrastructure for managing climate change

Contact information

Knowledge for Climate Programme Office

Secretariat:
c/o Utrecht University
P.O. Box 80115
3508 TC Utrecht
The Netherlands
T +31 88 335 7881
E office@kennisvoorklimaat.nl

Public Relations:
c/o Alterra (Wageningen UR)
P.O. Box 47
6700 AA Wageningen
The Netherlands
T +31 317 48 6540
E info@kennisvoorklimaat.nl

www.knowledgeforclimate.org