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EDITORIAL

From climate research to climate compatible development: experiences and progress in the Netherlands

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Abstract Over the past decades, significant experience has been gained in demand-driven research on climate change in many countries. In the Netherlands, a competitive call for proposals for large research programmes at the interface between policy, science and private sector was issued in 2001. Members of the Dutch climate research community proved they were able to develop two large research programme proposals which were funded: '*Climate changes Spatial Planning'* and its successor '*Knowledge for Climate'*. The programmes ran from 2004 to 2012 and from 2008 to 2014, respectively. Both programmes can be considered as a 10-year research programme experiment to develop knowledge about both the climate system and climate compatible development by crossing disciplines, institutions and national research funding strategies. Within this 10-year period, a trend can be observed in which a 'top-down' climate impact assessment approach is increasingly combined with a 'bottom-up' approach. Based on the 15 articles presented in this special issue (and others), we argue that this development has enriched both fundamental and applied research on climate adaptation. Despite the predominantly Dutch-oriented scope of the presented research, we believe that such experiences can be of international interest. Climate adaptation research finds itself in between global systems knowledge on the one hand and practical needs and experiences at the local, regional and national level on the other. This demands the utmost from all actors involved to enable an efficient and constructive flow and use of knowledge and expertise.

Keywords Climate adaptation · The Netherlands · Spatial planning · Governance · Research programmes

Introduction

Over the past few decades, significant experience has been gained in demand-driven research on climate change. Various accounts and historical reconstructions can be found in the literature that describe the development of climate change research at the global level (Doherty et al.

This special issue is dedicated to the memory of Piet Rietveld. Internationally recognised as one of the leading researchers in economic geography and among colleagues beloved as a wonderful person, both CcSP and KfC are proud to have worked with Piet intensively, not only in the field of research but also in programme management.

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2009; Pielke 2010a), at the European level (Termeer et al. 2012; Biesbroek et al. 2010) and at national level in different countries (Bauer et al. 2012; Greiving and Fleischhauer 2012). Studies at the national level are generally characterised by a thematic approach, such as spatial planning (Wilson 2006), agriculture and national resources (Pearson et al. 2011; Meinke et al. 2009; Steffen et al. 2011), flood risk management (Rosenzweig and Wilbanks 2010; Rosenzweig and Solecki 2010) or the governance of climate research (Pielke 2009; Sarewitz and Pielke 2007; Pielke 2010b; Termeer et al. 2011; Storbjörk 2007).

The Netherlands has a tradition of research on climate change, which goes back to the 1960s (Baede and Schuurmans 2008; Schuurmans and Baede 2008; RIVM 1987; RMNO 2001). Like in many other countries, research on the climate itself, as a system, goes back much earlier of course, with its origins in natural science and meteorology. According to the Royal Netherlands Meteorological Institute (KNMI), the first article in Dutch literature (van Genderen 1967) on the relationship between CO_2 and climate change appeared in 1967 and had very little societal impact. It was not until the early 1980s that Dutch climate policy began to take shape, parallel to the developing stage of the IPCC as an international intermediary (Schuurmans and Baede 2008; Driessen et al. 2009).

Looking back at those last 30 years, we make a distinction between three successive periods that characterise the development of climate research in the Netherlands:

Climate science and climate change (early 1980s–1990)

Is climate change caused by human agency? The hypothesis underlying this question was the scientific and social trigger for increasing the level of research on climate and climate change, with the implicit assumption of the oceans, ice, the hydrological cycle and the atmosphere being the major components of the climate system.

Climate science and climate policy (early 1990s–2001)

Which measures are needed to prevent or to mitigate climate change? An additional dimension of climate change research became the investigation of possibilities to lower the emission of greenhouse gases by mitigation policies through the alternative deployment of natural resources, land-use change (RIVM 1987) and encouraging the use of sustainable energy resources (wind, solar, water, biofuels) (Klostermann et al. 2009; Oikonomou and Jepma 2008). The feedback loops between the biosphere and land-use on the one hand, and other components of the climate system were increasingly taken into consideration (de Gier and Schuurmans 1998; van der Laan and de Kort 1998), also internationally (Steffen 2001). While the notion of land and land-use as an intrinsic part of the climate system was not new (Pielke and Avissar 1990; Pielke et al. 1991; Pielke et al. 1998), it was not until the late 1990s that it was acknowledged by a wider range of scientific disciplines.

Climate science, adaptation and climate compatible development (2001–present)

What are the effects of climate change, to what extent are they acceptable (Dessai et al. 2004; Paavola and Adger 2006), and if they are not acceptable, which societal agents should incorporate climate adaptation (Glantz 2003; Kabat et al. 2005b) into their long-term strategies? Climate change had become recognised as a two-sided coin, with not only a mitigation-side to it but also entailing an assignment for adaptation (Van Nieuwaal et al. 2009; Termeer et al. 2011). Furthermore, extra emphasis was put on the question: what kind of science-society and science-policy relationships do we need in order to translate climate change into social change (Driessen et al. 2010)?

In the Netherlands, this discussion encompassed not only climate change, mitigation and adaptation. Around 2000, the economical dimension of responses to climate change was also brought forward. In this period, funding programmes for climate research in the Netherlands were coupled with the policy objectives of the ministry of Public Transport & Water Management (V&W), the ministry of Agriculture, Nature and Food Quality (LNV), the ministry of Housing, Spatial Planning and the Environment (VROM) and the ministry of Economic Affairs (EZ). In 2001, a competitive call for proposals for large research programmes was issued by the national government. The government's objective was to strengthen the Dutch economic infrastructure by improving the Dutch knowledge infrastructure through knowledge transfer and valorisation of knowledge between science, policy and private sectors. The funding, which was € 802,000,000, came from national gas revenues (Ministry of Economic Affairs 2002a, b). A maximum of 50 % of the total budget of these research programmes was funded in this way, and the participating organisations were obliged to bring in the rest. This research funding philosophy resulted in 37 research and innovation programmes in the field of environmental sciences (Kabat et al. 2005a; Bouma et al. 2011; Zegveld 1988, 2003), and technology (Cramer and Zegveld 1991; Zegveld 1988). In many of these research programmes the objective was to make use of multiple scientific disciplines and to address environmental and socio-economic issues in a cross-sectoral way. This required a transdisciplinary research approach, while the conventional public research funding approach in the Netherlands, and also in Europe, was still mostly geared to maintain and reinforce disciplinarity (Vasbinder et al. 2010). In addition, this called for

a shift from focus on the production of disciplinary knowledge to more attention being given to interdisciplinary research approaches, the involvement of stakeholders in developing research agendas and research projects, and knowledge dissemination and application.

Members of the Dutch climate research community proved that they were able to develop two large research programme proposals, which were funded within a competitive context: *Climate changes Spatial Planning* (CcSP) and its successor *Knowledge for Climate* (KfC) (Kabat et al. 2005b; Van Nieuwaal et al. 2009). These programmes ran from 2004 to 2012 and from 2008 to 2014, respectively.

In both cases, one could speak of an attempt to combine research, climate policies and economic development in order to achieve 'climate compatible development' (Mitchell and Maxwell 2010) rather than 'climate adaptation' or 'climate proofing' (IPCC 2007; Adger and Barnett 2009) in the narrow sense. 'Climate compatible development' is a development that minimises the harm caused by climate impacts while maximising the many social and economic opportunities that result from low carbon urban developments and more resilient pathways (Mitchell and Maxwell 2010). Dwelling on the experiences from the programme management of both national research programmes, we observe a tendency from a more 'top-down' climate impact assessment approach to a more 'bottom-up' approach to the climate change issue within the Netherlands. By a top-down approach, we mean scenario-induced climate adaptation, in which impact-assessments guide research and policy. By a bottom-up approach, we mean processes aimed at climate adaptation that hinge on the vulnerability and resilience of specific regions and urban agglomerations and this emphasises the importance of close science-policy interactions. We argue that both approaches are necessary in order to translate insights from international climate change research to regional initiatives and experiences with climate compatible development and vice versa.

Objectives and approach of this special issue

The objective of this editorial is to position the presented research results contained in this special issue in the context of the shifts that have been detected in the above. The articles themselves mainly originate from the Dutch national research programme CcSP but many authors are also involved in the KfC programme. Figure 1 shows a tag cloud based on the 15 abstracts of the papers in this special issue. It reflects the themes addressed in this special issue.

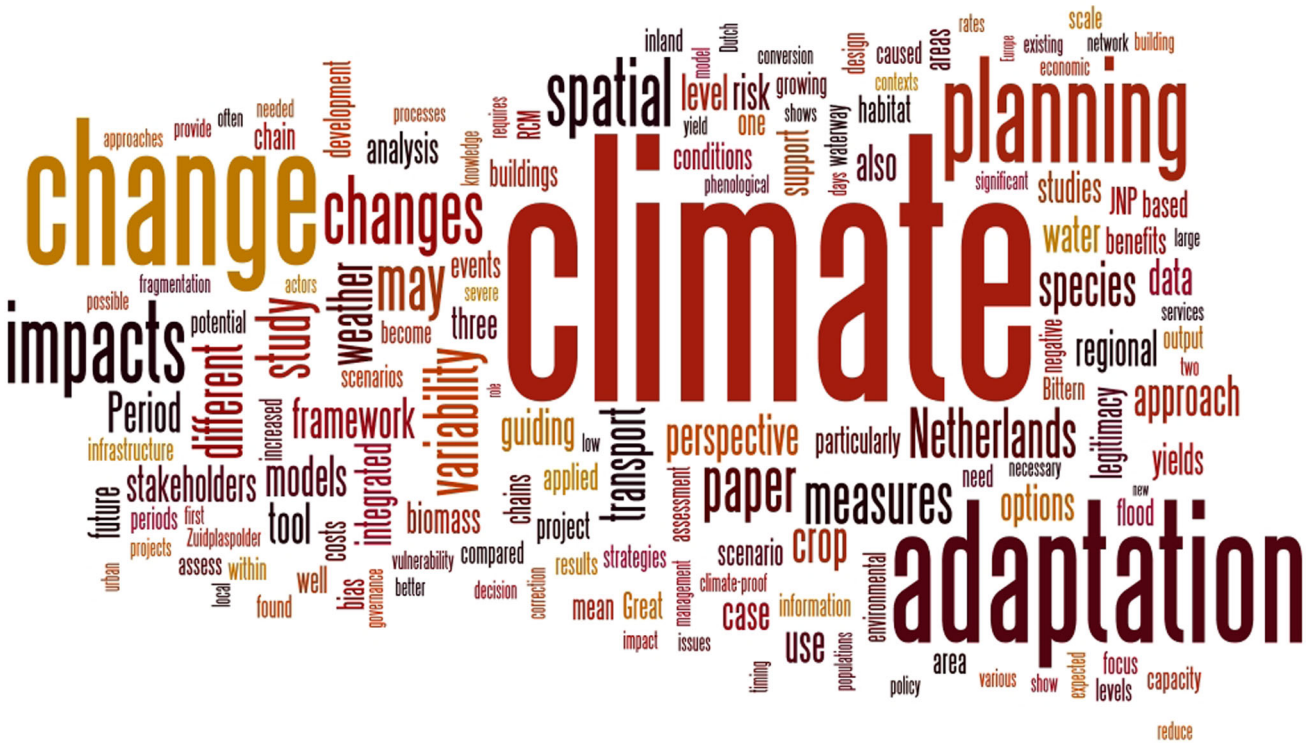

Fig. 1 Tag cloud (Feinberg 2011) based on the 15 abstracts in this special issue. The figure gives greater prominence to words that appear more frequently in the source text

Table 1 Overview of the papers contained in this special issue

Abbreviated title and authors	top-down/ Bottom-up	Disciplinary fields	Scale	Sector
Climate model research and scenario development				
Exploring the efficiency of bias corrections of regional climate model output for the assessment of future crop yields in Europe (Bakker et al.)	top-down	Crop science, Climatology, Software engineering	Europe	Agriculture
Framing climate uncertainty: using socio-economic and climate scenarios in assessing climate vulnerability and adaptation (Berkhout et al.)	top-down and bottom-up	Climatology, Social psychology, environmental sciences	Global (IPCC), national (the Netherlands), local (the North)	IPCC, Water management, Wind energy
Climate adaptation and scenario use				
Evaluating the effect of flood damage-reducing measures: a case study of the unembanked area of Rotterdam, the Netherlands (De Moel et al.)	Top-down	Hydrology, Economics, Climatology, Public administration	Rhine catchment, Rotterdam area	Water management, Insurance, Building construction
Climate proofing the Zuidplaspolder: a guiding model approach to climate adaptation (Reichwein et al.)	Bottom-up	Environmental Sciences, Landscape architecture	Local, regional	Spatial planning
Climate adaptation of interconnected infrastructures: a framework for supporting governance (Bollinger et al.)	top-down and bottom-up	Civil engineering, Economics, Logistics, Geosciences, Public administration	Local, regional	Urban planning, Road, Electricity, Drinking water
Synthesis of ecosystem vulnerability to climate change in the Netherlands shows the need to consider environmental fluctuations in adaptation measures (Van Bodegom et al.)	top-down	Landscape ecology, Soil science, Ecohydrology	National	Nature, the Netherlands Environmental Assessment Agency
Population dynamics of Great Bittern (Botaurus stellaris) in the Netherlands: interaction effects of winter weather and habitat fragmentation (Cormont et al.)	Bottom-up	Landscape ecology, Population ecology, Statistics	National	Nature conservation
Climate change and economic consequences for inland waterway transport in Europe (Jonkeren et al.)	top-down	Transport economics, Spatial economics, Hydrology	Rhine catchment, National	Navigation, Transport, Water management
Development and evaluation of climate policies				
An integrated computer based tool to assess economic and environmental implications of biomass delivery chains (Elbersen et al.)	Bottom-up and top-down	Landscape architecture, Environmental sciences, Plant production science, biotechnology	Europe, national, regional level	Agroforestry, Energy and Agriculture
Climate-proof planning for flood-prone areas: assessing the adaptive capacity of planning institutions in the Netherlands (Van den Brink et al.)	Bottom-up	Public administration, Environmental sciences,	Local level	Spatial planning, water management
Observed climate-induced changes in plant phenology in the Netherlands (Van Vliet et al.)	Bottom-up	Phenology, Ecology	Local and national level	Phenological networks, Citizen science
Costs and benefits of adapting spatial planning to climate change: lessons learned from a large-scale urban development project in the Netherlands (De Bruijn et al.)	Top-down	Economics, Environmental sciences	Local and national level	Water management, Spatial planning
Towards legitimate governance strategies for climate adaptation in the Netherlands: combining insights from a legal, planning, and network perspective (Van Buuren et al.)	Top-down and bottom-up	Environmental sciences, Public administration; Legal sciences	Regional level	Spatial planning and Water management

Table 1 continued

Abbreviated title and authors	top-down/ Bottom-up	Disciplinary fields	Scale	Sector
Climate Adaptation Services for the Netherlands: an operational approach to support spatial adaptation planning (Goossen et al.)	Top-down and bottom-up	Environmental sciences, Climatology, Architecture, Geography, Hydrology, Plant science, Geoscience, GIS	Regional level	Spatial planning and Water management
Towards design principles for joint knowledge production projects: lessons from the deepest polder of the Netherlands (Hegger et al.)	Bottom-up	Environmental sciences, Public administration	Local level	Spatial planning

Table 2 Some general characteristics of the CcSP and KfC programmes (data derived from societal and scientific synthesis reports that were written for review in 2012 (Kabat et al. 2011)

Characteristics	CcSP	KfC	Total
Research projects	53	>60[a]	>100
Scientific characteristics			
Initiated PhD trajectories	59	55	114
Scientific papers in international journals			>600
Socio-economic characteristics			
Co-financing partners	97	>100[a]	>100
Realised co-funding	44 million (€)	32 million (€)	76 million (€)
Programme funding (FES, BSIK)	40 million	46 million	86 million
Knowledge dissemination			
Unique Visitors www.klimaatonderzoeknederland.nl (2012)			27,987[b]
Total downloaded publications (2012)			316,919[b]

[a] Projects are still being initiated

[b] Personal communication: Fokke de Jong, web manager CcSP/KfC website

A fair defence can be put forward to consider both programmes as a 10-year research programme experiment to develop knowledge about both the climate system and climate compatible development by crossing disciplines, institutions and national research funding strategies. The research programmes share the objective to generate internationally competitive scientific results and to provide a knowledge-base that interactively supports practitioners on how to cope with climate change at the national, regional and local scale. The CcSP research programme having finished and the KfC research programme actively elaborating on the legacy of its predecessor provide a golden opportunity for the joint effort to produce this special issue. All four editors invited to work on this special issue were actively involved in managing the two research programmes.

The scope of this special issue, including the limited selection of articles (Table 1), does not allow our ambition to position the research results in the context of shifts in climate change research to be sustained by strong causalities and generalisation within an international context. However, reflections in Europe on climate research funding strategies are scarce, contrary to those in other research fields (Arnold 2004; Spaapen et al. 2007), and this encouraged us in our modest attempt to share the thinking in the Netherlands. In addition, the responsible climate research funding agencies and leading scientists of the two programmes not only evaluate scientific output but also frequently discuss the extent to which research within CcSP and KfC is relevant and applicable for actual decision-making processes on investments aiming to improve climate compatible development based on the criteria presented in Table 2. Also from this perspective is it considered interesting to reflect on this issue.

In order to focus and structure our analysis, three domains were selected. Although the two research programmes are independent, separately funded programmes, it is these three domains that CcSP and KfC share as the main column for the research being carried out and they were found to be the drivers for collaboration between the two programmes. These three domains also touch upon the core of development we aim to investigate:

- climate model research and scenario development;
- climate adaptation and scenario use;
- development and evaluation of climate adaptation policies.

It must be noted that these three domains do no justice to the variety and depth of research on climate adaptation in the two programmes. The papers presented in this special issue are a selection of the most relevant research outcomes so far. An exhaustive overview of research projects and

associated results can be found on the website of both programmes[1].

The analysis is carried out on the basis of documented accounts from both programmes, including articles and reports from the projects and the articles presented in this special issue. Special attention is given to the existence of features of 'top-down' as well as 'bottom-up' approaches (Adger et al. 2005a, b) and features of interdisciplinary and transdisciplinary research (Wesselink 2008, 2009) at both project and programme level. Experiences from the follow-up programme KfC supplied additional sources to reflect upon our findings.

The CcSP and KfC research programmes

The CcSP programme was originally organised in four main themes: climate scenarios, mitigation, adaptation and integration. This structure was chosen in consultation with the ministries involved and regional policy makers during the proposal development phase (2000–2004). This structure seems comparable with the three working groups of IPCC in 2001 but there are some subtle distinctions and different accents due to the national context. The research theme 'climate scenarios' covered not only research into the climate system (IPCC working Group 1) but also focused on tailoring climate information to support water managers and spatial planners. The Dutch government was critical about mitigation research in 2000–2004 because in face of the ratification of the Kyoto protocol (2004) mitigation policies to reduce greenhouse gas emissions and energy use were in their final stage of development. As a result, it was decided to narrow down research into mitigation to quantify greenhouse gas emissions related to land-use (Lauvaux et al. 2009; Hutjes et al. 2010), full carbon accounting (Hutjes et al. 2009; Nabuurs et al. 2008) and bio-energy chains (Cuppen et al. 2010; Elbersen et al. 2014). IPCC working group III (mitigation) has a much broader scope. The set-up of adaptation research was comparable with IPCC working group II and designed from both a sectoral and regional perspective. The projects under the theme 'integration' were meant to integrate activities within the former three themes with the aim of generating comprehensive decision-support frameworks for policy-making, while within the international climate research community 'integration' is often described as mainstreaming climate policies in other policy domains (Uittenbroek et al. 2013; Brouwer et al. 2013; Halsnaes and Traerup 2009; Yamin 2005; Buuren et al. 2013) or described as the interplay between adaptation and mitigation (Jordan et al. 2010). During the course of the programme it was decided to introduce a fifth separate theme for communication projects. The objective of the communication theme was to allow stakeholders to interact with the research agenda by informing them about projects at an early stage in order to increase the practical usefulness of the research results, also for stakeholders that were not involved in a particular project.

Climate (adaptation) research and practice became a 'booming business' in the Netherlands after 2005, and it turned out that the CcSP programme alone could not meet the rapidly increased demand and societal need for applied knowledge on climate adaptation. As a result, a new and complementary research programme, Knowledge for Climate (KfC; 2008–2013), was developed, which was approved by the Dutch Government for funding in 2007. The KfC programme consists of two research lines: (a) fundamental research on eight adaptation themes; (b) applied research on adaptation strategies for eight vulnerable areas in the Netherlands (so-called 'hotspots'). The KfC themes were flood risk management, freshwater supply, rural areas, cities, infrastructure and networks, climate projections, governance of adaptation and decision-support tools. The research themes were selected in dialogue with representatives of the relevant ministries and the regional hotspots teams. An important selection criterion was that the research results could be applied in climate adaptation measures and strategies at local, regional and/or national scale. The hotspots served as intermediary platforms to align knowledge needs and scientific research during the entire course of the programme.

Together, both programmes have initiated more than 100 research and knowledge dissemination projects (Table 2). Cooperation between scientific disciplines and policy-making was organised at programme and project level by research consortia. The project duration ranged from a few months to 5 years (projects involving PhD research). Coherence between the projects was emphasised and promoted through programme management by defining shared objectives, products and by organising programme-wide activities—programme meetings for instance—and international conferences, such as Deltas in times of climate change I (CcSP et al. 2010) and II (2014). This was a complex process that required a lot of effort, patience and stamina from both project leaders and programme management.

Many of the co-financing partners have participated in both programmes and include national financial resources which were primary allocated for universities and applied research institutes. In addition, co-funding was derived from governmental bodies at regional, national and international level (EU research programmes). Contributions from the business community were relatively small in both programmes.

Together, both programmes so far have published more than 600 scientific papers in international scientific journals in the field of hydrology, climatology, ecology,

[1] http://www.climateresearchnetherlands.nl

environmental sciences, climate science, public administration, economics, governance and planning. In conjunction with these scientific publications, knowledge was also disseminated by means of special issues in Dutch public magazines, contributions in media (newspapers, etc.), the Internet and social media.

Climate model research and scenario development

Apart from providing society with estimates of future climate conditions, it is necessary to remain alert about the many unknowns in the models, the observations, and the generated scenarios for temperature (van den Hurk et al. 2007), precipitation (van Haren et al. 2012) and sea level rise (Katsman et al. 2011). To give emphasis to this awareness, CcSP (and to a lesser extent KfC) followed a dual-course strategy in climate scenario research: one track aimed at generating tailored climate scenarios for a wide range of users, as exemplified by the paper about bias correction (Bakker et al. 2013) in this special issue. The other track focused on an increased understanding of the system and improved observational records, adequately merged into a regional climate model (RACMO) and a global model (EC-Earth).

Climate model developments

The RACMO climate model was revised (van Meijgaard et al. 2012) and refined with new knowledge about the boundary layer (Baas et al. 2008), aerosols (Weijers et al. 2011; Ten Brink et al. 2009), soil hydrology parameters (Jong et al. 2008), cloud formation (Bouniol et al. 2010; Schutgens and Roebeling 2009) and evaluated with European remote sensing data (Wipfler et al. 2011). This was done in a multidisciplinary approach in which insights from physics, soil science and hydrology (Brauer et al. 2009), derived from monitoring projects (Russchenberg et al. 2011), were combined with meteorology.

Climate changes spatial planning cooperated with international observation campaigns in the north-western North Atlantic (Hendry et al. 2007; Kohl et al. 2003). Hydrographic properties of the pre-industrial run of eight coupled climate models, used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), were compared with observations from the World Ocean Circulation Experiment in the north-western North Atlantic (De Jong et al. 2009). The simulations with these coupled climate models differ significantly from regional observations of ocean thermal stratification in the north-western North Atlantic. The subsurface temperatures in the climate models that were used are higher compared to the observations in the North Atlantic (De Jong et al. 2009). A large natural variability at all water mass horizons could be described from daily to multi-decadal time scales (van Aken et al. 2011). Because of that natural variability, one may expect that the West European climate that depends on heat flux from the Atlantic Ocean will be more variable than currently assumed in climate models used for climate scenarios simulations. These new insights are taken into account within the next generation of Dutch climate scenario's (KNMI-next), and the development of EC-Earth (Hazeleger et al. 2010). Within EC-Earth, it has been recognised that biogeochemical and human processes interact with the physical climate system.

Scenario development

The paper of Bakker et al. and Berkhout et al. in this special issue (Berkhout et al. 2013) demonstrate which steps are necessary to make tailored general climate scenarios for water management, agriculture and the energy sector. In addition, Berkhout and co-authors argue that scenario approaches need to be matched to the frames of stakeholders who are situated in specific decision contexts. Bakker et al. exemplifies how data from regional climate models (RCMs) could be corrected for bias in observations, in order to improve crop yield simulations with the crop model WOFOST(Boogaard et al. 2013).

Socio-economic and land-use scenarios were not developed but in most research projects adopted from the national environmental and socio-economic agencies (Van Drunen and Berkhout 2009). The use of these socio-economic scenarios is exemplified in this special issue at national level for water transport (Jonkeren et al. 2013) and flood risk management (Moel et al. 2013), while experiences at regional level are described for case studies in the area of Rotterdam (Moel et al. 2013; Goosen et al. 2013). In CcSP/KfC studies for agriculture (Schaap et al. 2011; Hermans et al. 2010; Mandryk et al. 2012; Reidsma et al. 2010) and bio-energy chains (Elbersen et al. 2014), the IPCC-SRES scenarios were used as the basis (Nakicenovic et al. 2000).

The dual-course strategy enabled climate scientists to identify uncertainties at the level of the climate system while also the needs for knowledge from stakeholders and other scientific disciplines were identified within the tailoring process. An important challenge for climate compatible development is to co-produce knowledge (Cash et al. 2006; Edelenbos et al. 2011) about vulnerability and resilience to climate change of society based on both 'global' climate change scenario's and regional determined socio-economic scenario's (bottom-up).

Climate adaptation and scenario use in the Netherlands

The papers in this special issue illustrate the diversity in how scenarios were used in Dutch practice in spatial planning, water management, nature conservation and infrastructure policy. Scenarios were used regarding flood risk reduction measures at the national level (Vellinga et al. 2008, 2009; Te Linde et al. 2011; Kabat et al. 2009) and at the level of regional water systems in urban areas situated both below (Brink et al. 2013; Moel et al. 2013; Groot-Reichwein et al. 2013) and above sea level (Buuren et al. 2013). Many of these research projects were inspired by the risk approach (Vlek 2010a, b; Hall et al. 2006), which is also a characteristic of climate compatible development and climate proofing. The risk approach is also adopted by the national Delta programme. One of the implicit objectives of the National Delta programme (Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, Agriculture and Innovation 2011) is to embed knowledge about risk analysis, scenario use and tipping points analysis (Kwadijk et al. 2010; Werners et al. 2013) into flood risk management and to a lesser extent into water supply management.

The assignment for spatial planning is of a kaleidoscopic nature. The vulnerability of urban areas to prospected flood risks and heat stress has found its way to the policy-making agenda of the Netherlands. The framework of multi-layered safety (Ministry of Infrastructure and the Environment 2009) in the national water plan is also inspired by the risk approach and climate adaptation. Within this framework, investments have been made not only in the prevention of floods, but also in the prevention of damage in the unlikely case of an emergency, by taking adaptive measures in spatial development and in evacuation potential. However, at regional policy-making level, this concept is recognised as an adaptation option, such as in the Rotterdam region (Moel et al. 2013), but is not yet common practice or even doubted as is the case in the province of Zeeland (Broekhans and Correljé 2008). Current research in the Netherlands elaborates on the paradigm shift that 100 % safety can never be guaranteed, and therefore residual risks and subsequent damages should not be ignored. This opens up new opportunities for research and innovation.

Surprising to some, climate change also implies issues of water shortage in the Netherlands. Fresh water supply is recognised as one of the main concerns in that respect, but low water levels in the Rhine will also cause significant welfare losses due to increased transport prices whether waterway transport becomes more and more congested (Jonkeren et al. 2013). The vulnerability of infrastructure and networks in general is increasingly recognised as an indispensable part of the climate adaptation research agenda (Bollinger et al. 2013). Amidst issues within our built environment, we must not forget the ecological structures with which they are, and should be, connected (Groot-Reichwein et al. 2013). Climate adaptation research in the Netherlands is building up a strong curriculum on research into the impact of climate change on the interactions between the abiotic (water, soil, atmosphere) and biotic components (species) of ecosystems (Bodegom et al. 2013; Vliet et al. 2013). The paper on the great bittern (Cormont et al. 2013) is one of a very specific kind, but it does illustrate how specialised the field has become.

With the support of both research programmes, significant progress has been made on using the risk approach in water policy-making and climate science at different scales in the Netherlands. This is one step forwards towards climate compatible development. Knowledge about climate risks and adaptation strategies in Dutch water management is also being increasingly co-produced by combining knowledge from the different sectors involved (Verkerk and Van Buuren 2013; Hegger et al. 2012b). However, it still remains a challenge to do this, from other policy perspectives too, and to combine the insights gained.

Development and evaluation of climate policies

Adaptation to climate change entails the quest for balancing short-term agency and long-term horizons. Many studies in the field of climate policies (Davoudi et al. 2010; Wilson 2006; Adger et al. 2009; Termeer et al. 2011), natural resources management (Adger et al. 2005c) and disaster risk reduction have shown that it is difficult to effectively use these inter-linkages, even if they are obvious, because investment costs, benefits and side effects of national adaptation strategies are, for example, not equally distributed between different geographical scales, different regions and between socio-economic groups, also exemplified in the study about the Zuidplaspolder (Bruin et al. 2013).

Therefore, not surprisingly, climate adaptation requires the development, implementation and evaluation of policy strategies and policy measures. Not taking action is not an option, yet investing too much in the wrong direction is a pitfall everybody would want to avoid. Developing the adequate policies is not only crucial for effective climate compatible development, there is also an increasing awareness that there is much more to gain in terms of efficiency. We argue that because of all the uncertainty, climate adaptation is to a large extent learning by doing and evaluation and monitoring should be part of all climate policies. The interaction with stakeholders throughout the entire process appears to pay off (Brink et al. 2013; Buuren et al. 2013; Goosen et al. 2013; Hegger et al. 2012b; Hegger et al. 2012a). Modelling and monitoring tools (Goosen et al. 2013) can be instrumental in drawing the

bigger picture in which the various stakeholders not only recognise themselves, and *feel* that they are recognised; it also enables a true dialogue on the wicked problem at stake. More flexible institutional arrangements are proposed to put those insights into practice (Brink et al. 2013). Particularly pilots and experiments at the regional and local scale can be of value in taking knowledge production further. This special issue incorporates three papers on such a case, the Zuidplaspolder (Bruin et al. 2013; Groot-Reichwein et al. 2013; Brink et al. 2013).

The papers in this special issue illustrate how knowledge to underpin adaptation and mitigation policies can be developed at different scales—ranging from national to local, and for different sectors. However, it remains a challenge how to interlink top-down and bottom-up research at different scales.

Conclusions

Experiences from climate adaptation research in the Netherlands indicate a shift from what we have labelled a 'top-down approach' to the inclusion of more 'bottom-up approaches' to climate adaptation research. Based on the articles presented in this special issue, among other things, we argue that this development has enriched both fundamental research and applied research on climate adaptation, finding its way particularly towards climate compatible development at the national, regional and local scales.

Despite the predominantly Dutch-oriented scope of the research, we believe that such experiences can be of international interest. Hence, we encourage subsequent initiatives from elsewhere in order to accommodate and stimulate international comparison. We firmly believe that the crossing of scales from a geographical, temporal and sectoral perspective will become more and more important in conducting research on climate adaptation. Alternating top-down *and* bottom-up approaches will be one of the major challenges in that respect. Climate adaptation research finds itself in between IPCC level global systems knowledge on the one hand, and practical needs and experiences at the local, regional and national level on the other. This demands the utmost from all actors involved to enable an efficient and constructive flow and use of knowledge and expertise.

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