EEA Report | No 3/2013

Adaptation in Europe

Addressing risks and opportunities from climate change in the context of socio-economic developments

ISSN 1725-9177

European Environment Agency

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Layout: EEA/Pia Schmidt

Luxembourg: Publications Office of the European Union, 2013

ISBN 978-92-9213-385-6
ISSN 1725-9177
doi:10.2800/50924

Environmental production
This publication is printed according to high environmental standards.

Printed by Rosendahls-Schultz Grafisk
— Environmental Management Certificate: DS/EN ISO 14001: 2004
— Quality Certificate: DS/EN ISO 9001: 2008
— EMAS Registration. Licence no. DK – 000235
— Ecolabelling with the Nordic Swan, licence no. 541 176
— FSC Certificate – licence code FSC C0688122

Paper
RePrint — FSC Certified 90 gsm.
CyclusOffset 250 gsm.
Both paper qualities are recycled paper and have obtained the ecolabel Nordic Swan.

Printed in Denmark

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The EEA would like to acknowledge and thank the following persons for having provided comments to the draft report:

European Commission, other agencies and international organisations

Alfonso Gutierrez Teira (DG Climate Action), Bettina Menne (WHO-Europe), Carlo Lavalle (JRC), Fina Ambatlle (Catalan Office for Climate Change (COCC), CTP/OPCC), James Creswick (WHO-Europe), Jesús San Miguel (JRC), Joan Canton (DG Climate Action), Juan Perez Lorenzo (DG Climate Action), Jürgen Vogt (JRC), Julian Wilson (JRC), Jutta Thielen (JRC), Karin Zaunberger (DG Environment), Marco Fritz (DG Environment), Marco Onida (Alpine Convention), Maria Fuentes Merino (DG Agriculture and Rural Development), Maria Pittman (DG Health and Consumers), Rachel Burbidge (EUROCONTROL), Tanja Wolf (WHO-Europe), Wolfram Schrimpf (DG Research and Innovation).

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A series of examples that illustrate adaptation in practice in Europe is provided in Chapter 2 of this report. This information is based to a large extent on previously published material. The EEA would like to acknowledge the organisations that have undertaken the critical work of collecting and documenting adaptation measures.

Foreword

Climate change is now a major part of planning for the future. Around the world, the extent and speed of change is becoming ever more evident and as reported in the EEA's 2012 *Climate change, impacts and vulnerability in Europe*, climate change is already causing a wide range of impacts on society and the environment. While reducing greenhouse gas emissions, there is also a need for society to adapt. Otherwise damage costs will continue to rise.

Adaptation is not simply about doing more, it is about new ways of thinking and dealing with risk and hazards, uncertainty and complexity. It will require greater public participation to address questions of social need and to find suitable adaptation pathways. European society has the opportunity to heed the lessons of past experience and adopt a precautionary approach, anticipating and minimising many future hazards whilst stimulating innovation. Climate adaptation requires precautionary science and approaches, with an emphasis on probability and multiple reactive thresholds, rather than a reliance on the statistics of the past. There is also scope for increased complementarity between adaptation and mitigation actions.

Sixteen EEA member countries (including fifteen EU Member States) have already developed national adaptation strategies, and twelve more are in the process of doing so. A wealth of regional and local responses is also emerging, tailor-made to address specific conditions and needs. There is no 'one-size-fits-all' approach to adaptation. Social and economic contexts, as well as local environmental impacts, play essential roles in shaping adaptation responses.

Adaptation is an expanding area of work for the European Environment Agency — this report is the first comprehensive Agency report on this subject — and one which we and our stakeholders expect to see increasing in importance in the future. In 2012 the European Commission and EEA launched the European Climate Adaptation Platform (climate-adapt.eea.europa.eu) where users can access and share a wide range of information including adaptation case studies, potential adaptation measures and tools that support adaptation planning. We will continue to improve the Climate-ADAPT, assessing the latest information and providing policymakers with analytical work that helps them plan and implement adaptation actions.

The Agency is also investing in improving the knowledge base in areas where there is a deficit of information and assessments, such as on the costs and benefits of adaptation; reviews of actions implemented by the business and private sector; indicators for monitoring and evaluating adaptation; and on the resilience of European territories in relation to green infrastructure and spatial planning.

Time is not on our side. We need to work in parallel on many issues, and assessment, evaluation and learning-by-doing are all important elements of what is required. Supporting actions through sharing knowledge and providing information, as in this report, will be how the EEA can best play its part in building the basis for better informed decision-making on adaptation at EU and country level.

Prof. Jacqueline McGlade
Executive Director

Executive summary

This report provides policymakers across Europe, at different levels of governance and stages of policy formulation, with information that can be used to support adaptation planning and implementation. Specific parts of the report are therefore targeted at different audiences.

This report draws on the experience of existing adaptation strategies and actions, promotes better informed decision-making in key vulnerable sectors and improved resilience across the EU. It supports the implementation of the EU Strategy on Adaptation to Climate Change.

Adaptation consists of actions responding to current and future climate change impacts and vulnerabilities (as well as to the climate variability that occurs in the absence of climate change) within the context of ongoing and expected societal change. It means not only protecting against negative impacts, but building resilience and also taking advantage of any benefits from these changes. The earlier we plan adaptation responses, the better equipped we will be to cope with challenges.

Adaptation and mitigation (i.e. the reduction of greenhouse gas emissions) are complementary actions, and both are EU priority areas for tackling climate change. Adaptation has the potential to support overarching policy objectives, such as 'Europe 2020 — Europe's growth strategy', and the transition to a sustainable, resource-efficient, green, and low-carbon economy.

The key findings from this report are grouped below in the form of key facts and three challenges that must be addressed when approaching adaptation policymaking in Europe. Other key findings are given at the start of each chapter.

Key facts

- Examples of implemented actions show that adaptation of both natural and human systems is already taking place across Europe.
- There are 16 EEA member countries to date that have developed national adaptation strategies (nine more than in 2008) and some of these countries already have action plans in place. National adaptation strategies address primarily the water, agriculture and forestry, biodiversity, and human health sectors. Twelve additional EEA member countries are currently preparing a national adaptation strategy, and 15 in total have already established web portals. Some transnational regions (such as the Danube, the Baltic, the Alps and the Pyrenees) and cities have developed adaptation strategies or are currently developing them.
- At EU level, instruments for implementing adaptation policy include key mechanisms such as cohesion funds, agriculture funds, and infrastructure funds, as well as funds from the LIFE+ programme. These are critical to integrate adaptation into EU policy — a process known as 'mainstreaming' of adaptation.
- The European Climate Adaptation Platform (Climate-ADAPT, http://climate-adapt.eea.europa.eu) is an important source of information on adaptation in Europe. It supports stakeholders at all levels of governance by sharing a broad set of information on climate change risks, EU sector policies, adaptation practices, national initiatives, and decision-support tools. Climate-ADAPT includes key results of EU research, INTERREG and ESPON projects that have strengthened the EU's knowledge base on adaptation.
- The assessment of the costs and benefits of adaptation actions — at European, member country, and local levels — is an emerging field of work. Limited information on costs and benefits is available at present, and this information has to be considered with care as there is still much work to be done on improving assessment methods.

Challenge one: coherent approaches

1. European society is set to face many changes, including to its economy, population, environment, and climate. Adapting to these changes is a challenge and an opportunity for Europe and will require strengthening the resilience and adaptive capacity of economic sectors, cities and businesses. Adaptation provides an opportunity for synergies and spill-over benefits if Europe implements adaptation measures in a coherent way, by ensuring that policies are integrated and working toward similar goals.

2. A key challenge for EU adaptation policy is to ensure policy coherence across its many sectoral policies, integrating Europe's efforts to create a sustainable, resource-efficient, green, low-carbon, and climate-resilient economy.

3. A related challenge for EU adaptation policy is to ensure the effectiveness, efficiency and coherence of action across the various levels of governance. EU adaptation policy should take into account national strategies and plans as well as actions at transnational and city levels.

4. The Climate-ADAPT website supports the development of coherent adaptation policies by encouraging the sharing of experiences, and by providing information on transnational, national and sub-national adaptation actions in European countries.

Challenge two: flexible approaches

1. Adaptation policy responses ought to be tailor-made to address regional and local conditions and needs, and reject a one-size fits all approach. These responses must consider contextual factors such as socio-economic, technological, cultural, environmental and policy processes.

2. Adaptation policy responses ought to be flexible in taking into account the progress made in the scientific understanding of disaster risks, decadal climate variability, and long-term climate and socio-economic changes. This understanding is evolving and lessons are being learned from implementing actions. Adaptation policy must be flexible enough to deal with this. It is important to adopt an 'adaptive management' approach, which means adjusting our plans to these conditions as they unfold, taking account of uncertainty over future developments, and constantly updating our adaptation policy with new information from monitoring, evaluation and learning.

3. This flexibility can also be helped by using different types of adaptation measures. For example, implementing a combination of 'grey' (i.e. technological and engineering solutions), 'green' (i.e. ecosystembased approaches) and 'soft' (i.e. managerial, legal and policy approaches) adaptation options is often a good way to deal with the inter-connections between natural systems and social systems.

Challenge three: participatory approaches

1. The involvement of stakeholders (policymakers, NGOs, businesses, citizens) is important in creating a sense of 'ownership' in adaptation policy, a critical factor in the success of adaptation implementation. Stakeholder involvement also helps to improve the coherence of adaptation actions and builds adaptive capacity in the wider society. Further guidance on how to best involve stakeholders would be helpful to adaptation policymakers and other stakeholders alike.

2. Multi-level governance bridges the gaps between the different levels of policy and decision-making and provides opportunities for ensuring key actors are involved. It is also important that all levels of governance (local, regional, national, transnational and European) participate in adaptation implementation in a coordinated and coherent way.

3. In most countries, the private sector does not yet seem to be fully integrated into adaptation policy processes. This is because national frameworks and research activities often do not explicitly prioritise topics related to the economy and business. There is therefore limited information about adaptation measures being taken by the private sector. An exception to this is the insurance sector where the level of awareness and of action on adaptation is relatively high.

4. There will continue to be a need for support tools for adaptation decision-making, such as the website of Climate-ADAPT and the national adaptation websites. These websites help to achieve better involvement of stakeholders across all levels of governance.

Scope and intended users of this report

Climate change is a reality. Its effects are serious and potentially very costly for European countries and their citizens, businesses, regions and cities. In the coming years, one of the greatest challenges of public policy will be to adapt our economy and society so it can cope with — and even thrive under — the effects of climate change. Fortunately, some adaptation responses are already being implemented across Europe.

This report aims primarily to inform and support the work of those policymakers who are formulating adaptation policy or will be in the future. It is focused on supporting the development of EU adaptation policy across governance levels, and in particular the implementation of the EU Strategy on Adaptation to Climate Change. It will also be of relevance to national and regional authorities, and to private stakeholders involved in either planning or implementing adaptation actions.

Adaptation policy is still under development at EU, national and regional levels. This is why the examples in this report of adaptation measures that have already been implemented are so relevant. The examples provide a knowledge base of policy-in-action, giving the context of the adaptation measure, the factors crucial to its success, and the policy tools used to implement it.

Climate change and socio-economic development are both intrinsically subject to uncertainty. Nevertheless, this report identifies key areas in which adaptation action may be able to reduce social, environmental, and economic risks and strengthen resilience across Europe. These areas present promising prospects for future adaptation policy work by the EEA.

This report, together with the European Climate Adaptation Platform (Climate-ADAPT) ([1]), provide building blocks to help fill the gap in adaptation data and information in Europe. This will help to strengthen the so-called 'knowledge base' — the assessments based on this data and information. By delivering an overview of key developments in the field of adaptation, this report and Climate-ADAPT also allow policymakers and stakeholders to learn from adaptation experience elsewhere. For a comprehensive account of the state-of-play of adaptation and vulnerability in Europe, there is a need for additional information. This would have to include databases and reviews of national and sub-national adaptation strategies, as well as dedicated thematic analysis on a range of topics. Fruitful topics for study could include the inter-linkages between climate change adaptation policy and mitigation policy (e.g. in forestry), or the international dimension of climate change and its potential impacts on Europe (e.g. environmental/climate change migration, food prices and security, the vulnerability of the EU's outermost regions).

([1]) The European Climate Adaptation Platform (Climate-ADAPT; http://climate-adapt.eea.europa.eu) is a resource tool and the EU entry point to information and knowledge base on climate adaptation. It includes indicators, case studies, state-of-play of EU and national policies and supporting instruments. Climate-ADAPT strengthens information and knowledge-sharing across stakeholders at all levels of governance in Europe.

How to read this report?

This report can be read in a number of different ways depending on the reader's main concerns. Some chapters provide better starting points for those with specific interests or who have already some familiarity with adaptation.

Specifically, readers interested in having an overview of the adaptation challenge and examples of implemented actions across Europe should start with Chapters 1 and 2. Readers seeking an overview of adaptation policymaking at EU and national levels should start directly with Chapter 3. Finally, readers who are familiar with adaptation from both a content and policy perspective, might want to focus on Chapter 4, which reviews key issues that have the potential to shape to a large degree the future of adaptation in Europe. The road-map figure below depicts the logic of the report and how the chapters connect to each other.

Chapter 1 frames adaptation to climate change within the context of broader socio-economic change. It also discusses how adaptation fits within other EU policy initiatives and concepts such as 'Europe 2020 – Europe's growth strategy', the Resource Efficiency flagship initiative, and sustainable development. It argues that adaptation both presents a challenge to European society, and provides opportunities to build resilience within human and natural systems.

Chapter 2 provides a series of examples that illustrate adaptation in practice in Europe. It presents the 'lever s' (policy tools used at EU level to assist the implementation of adaptation measures), and offers a basis for learning from experiences about the factors that contribute to successful adaptation action, and the possible obstacles that can hinder it ([2]).

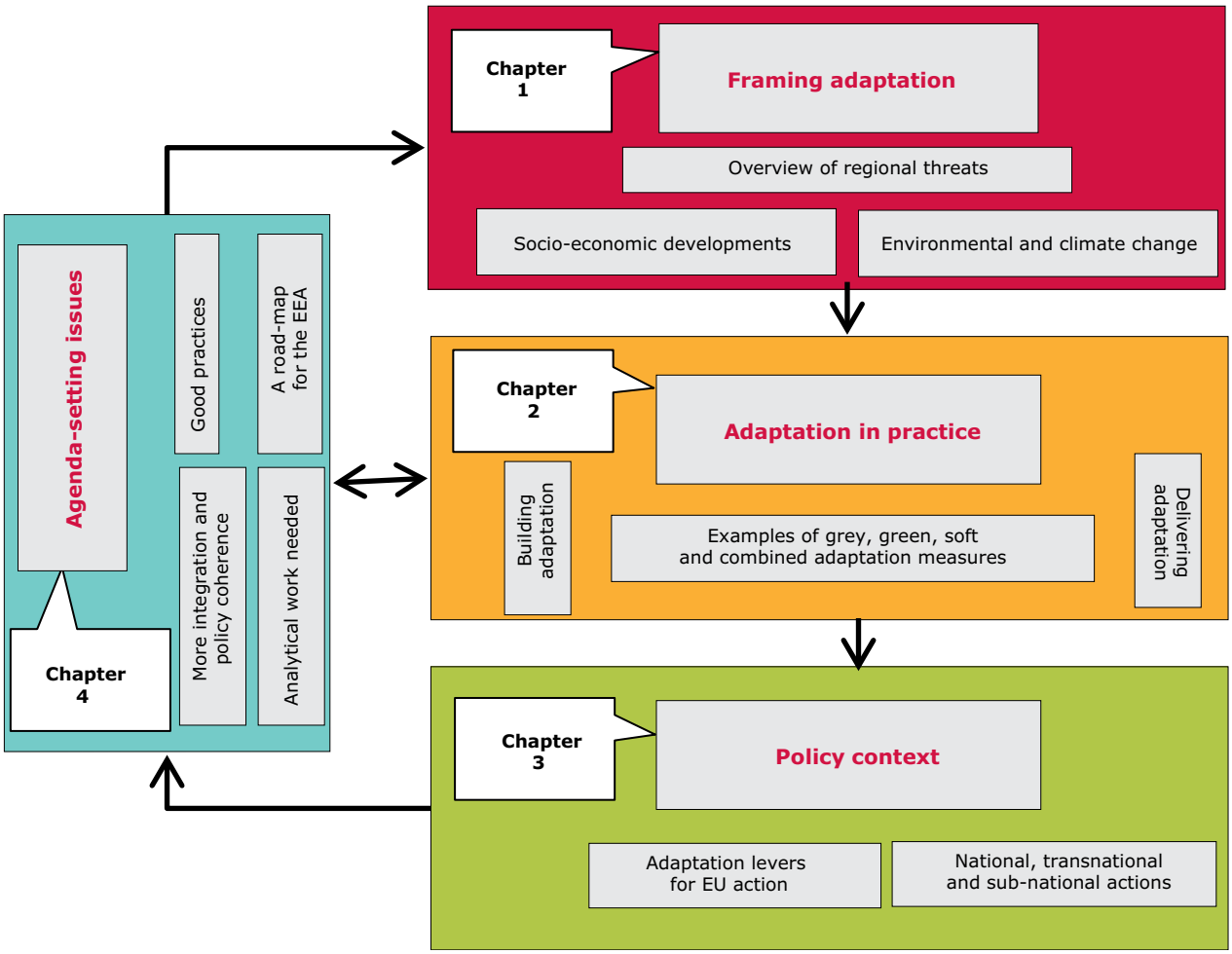
Chapter 3 reviews the European policy context within which adaptation is being strategically planned, supported and implemented. It describes a set of key levers for adaptation decision-making at EU level, as well as national, sub-national and transnational initiatives.

Chapter 4 addresses key issues that will shape the future of adaptation in Europe.

This report complements the recently published EEA report entitled *Climate change, impacts and vulnerability in Europe — An indicator-based report* (EEA, 2012c). The latter provides the scientific and analytical background information on climate change risks across European regions. These two reports are complementary in their approach in that the *Climate change, impacts and vulnerability in Europe* report follows an indicator-based approach, whereas the present report takes a policymaking and empirical (i.e. examples of adaptation) perspective.

([2]) EU adaptation levers refer to all EU policy instruments and mechanisms supporting adaptation directly or indirectly falling under the pillars of the EU approach, i.e. strengthening the knowledge base, integrating adaptation into EU policies (mainstreaming), using a combination of policy instruments to ensure effective delivery of adaptation and working in partnership with the Member States and strengthen international cooperation.

Road-map to the report



1 Framing adaptation

Key messages

- Climate change threatens the different regions of Europe in different ways, although all regions will experience climate change through a mix of gradual changes (such as increasing temperature or changes to biodiversity) and rapid ones (such as flooding). Opportunities from climate change are expected to be limited to some areas of Europe and some sectors.
- Adaptation is a response to risks (and potential benefits) caused by climate variability and climate change in the context of continuing socio-economic development. It is vital that Europe acts now to implement a programme to reduce its vulnerability, and to integrate adaptation into all sectors in a way that takes into consideration the wider context of social change. This will help deliver a resilient society, supported by a sustainable, green economy.
- Adaptation options can be grouped under three broad categories: 'grey' options that rely on technology and civil engineering projects; 'green' options that make use of nature; and 'soft' options that aim at altering human behaviour and styles of governance. Often, implementing a combination of these measures is an effective way to ensure resilience.
- Climate change adaptation measures require the integration of different levels of governance (European, national, regional, local) and different sectors of our economy and society. It also requires cooperation between different regions. This complexity presents a challenge, by requiring 'horizontal' and 'vertical' integration of policies. The integration of policy areas essential for adaptation policy means the EU has to 'mainstream' climate change adaptation by including adaptation measures in its sectoral policies. This will offer the potential for synergies and spill-over benefits when adaptation policies are successfully coordinated.
- Just like climate change, the continuous process of socio-economic change in the developed world can also be a cause of vulnerability. Researchers acknowledge the interaction of these two factors and are currently working on models that take this into account. More research work is needed to this regard to reach a more accurate assessment of future risks and vulnerability.

1.1 Climate change and related societal change: a key challenge for Europe

The climate is changing across the globe, and changes in global and regional temperatures are already modifying weather patterns, causing a number of impacts and increasing the vulnerability of regions, economic sectors and communities. In some areas of Europe and for some sectors, climate change might provide opportunities in future.

Even if greenhouse gas (GHGs) emissions stop today, our past emissions mean that climate change will continue for decades. Adaptation to a range of plausible future temperature increases is therefore a necessity, and the degree of adaptation needed will depend on the level of vulnerability and adaptive capacity of the system at stake. Adaptation and mitigation (i.e. reduction of GHG emissions) are complementary actions and priority areas for tackling climate change.

Climate change is one of the key drivers of global environmental change and has far-reaching consequences. Most studies suggest that climate change will — either directly or indirectly — challenge European society with economic, environmental, societal, geopolitical and technological risks ([3]). These risks may aggravate or interact with other pressures that are challenging

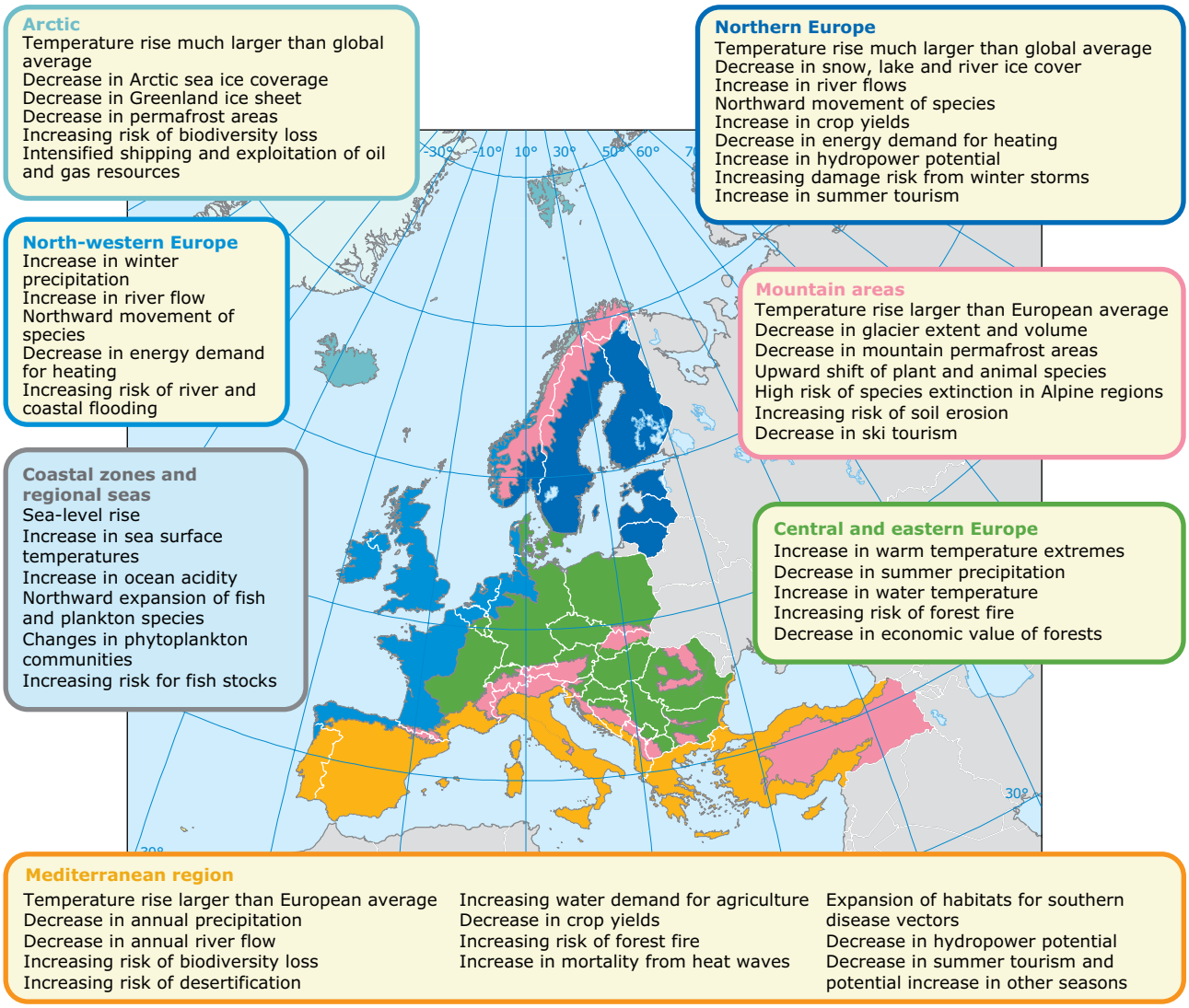
([3]) Economic risks: volatility in food and raw material prices; under-investment in infrastructure; economic downturn. Environmental risks: droughts and desertification, extreme weather, water scarcity. Societal risks: diseases, pandemics, migration. Geopolitical risks: terrorism, corruption, governance gaps. Technological risks: information gaps (WEF, 2010).

the security, health, quality of life, and wellbeing of Europeans ([4]).

The impacts of climate change vary across Europe, but nearly all parts of the continent are likely to feel its effects. Vulnerable regions include the Arctic; northern, north-western and central-eastern Europe; the Mediterranean basin; cities and urban areas; mountain areas; coastal areas; river flood prone areas; islands; and outermost regions.

Climate change presents Europe with challenges that range from the gradual — increases in temperature, loss of biodiversity, and rising of sea levels — to the sudden and extreme, such as greater potential for storms and flooding (for an overview of regional climate change impacts and vulnerabilities, see Map 1.1 and EEA, 2012c). Human health in Europe is at risk from events such as heat waves, while society more broadly is at risk from the stress placed on communities, infrastructure and the economy by phenomena such as floods; droughts and water scarcity; lower crop yields; and changing patterns of tourism. Climate change will directly or indirectly affect all economic sectors, regions and citizens, although to different degrees depending

Map 1.1 Key observed and projected impacts from climate change for the main regions in Europe



Source: EEA, 2012c.

([4]) Together with equally important issues such as: freshwater extraction, urban sprawl, land-use changes, agricultural intensification, depletion of natural capital, loss of biodiversity, consumption patterns and other forms of socio-economic development.

on their coping and adaptive capacities as well as their location. Climate change is also expected to provide opportunities in some areas of Europe and for some sectors (e.g. enhanced forest growth and agricultural yields in northern Europe). In addition to disrupting existing patterns of social organisation, the consequences of climate change will also have feedback effects on future plans for socio-economic development, for example affecting settlement patterns in vulnerable regions like coastal zones, flood plains, mountains, and cities, as well as the Mediterranean basin and the Arctic. The development of additional EU-wide data and information sources will further support the assessment of threats and opportunities from climate change in Europe.

Socio-economic development in Europe has the potential to exacerbate the impacts of climate change and vice versa. For example, changes in land-cover and land-use such as through urban sprawl and 'soil sealing' (the covering of land with impervious materials such as concrete, housing or tarmac) may worsen the effects of floods, or heat island effects in urban areas.

Natural systems provide vital ecosystem goods and services for many human activities including agriculture, forestry, fisheries, tourism and the supply of clean water and air. The impacts of climate change on natural systems are expected to be far-reaching — for example, the loss of biodiversity in terms of species, habitats and ecosystem functions and services. This is likely to have consequences on 'human systems' (human health, society and the economy) such as by lowering economic output or the quality of life.

The magnitude and diversity of climate change impacts on human and natural systems in Europe calls for adaptation responses that both reduce the vulnerability of these systems — for example through technological solutions — and further strengthen their resilience — for example through ecosystem-based approaches and managerial options. At EU-level, the integration and mainstreaming of climate change in sectoral EU policies is the key policy 'lever' (areas where the EU has tools to act at its disposal) for advancing adaptation and alleviating pressures on human and natural systems. It builds upon the corresponding EU instruments and funds, such as river-basin management plans; flood and hazard mapping; structural, cohesion, agriculture and infrastructure funds; LIFE+ instrument; protected natural areas; and 'green infrastructure' (see further details in Section 3.1).

A number of issues appear central to successfully implementing adaptation responses in Europe, including: generating adequate funding; building governance structures; providing incentives for the diffusion of innovation; and managing water and land to protect natural systems and preserve vital ecosystem goods and services.

1.2 What is adaptation and what can be done?

Adaptation consists of actions responding to current and future climate change impacts and vulnerabilities (as well as to the climate variability that occurs in the absence of climate change) within the context of ongoing and expected societal change ([5]). It means not only protecting against negative impacts of climate change, but also building resilience and taking advantage of any benefits it may bring. The earlier we plan adaptation responses, the better equipped we will be. In many respects, adaptation can be seen as a process of managing the different assets that sustain us. These assets include built infrastructure (such as roads and railways) and our natural environment, as well as our culture, society and economy.

Adaptation responses can be grouped under three broad categories ([6]):

- 'Grey' actions: technological and engineering solutions. Examples include: building or

([5]) Adaptation is defined by the IPCC as the *adjustment of natural or human systems to actual or expected climate change or its effects in order to moderate harm or exploit beneficial opportunities* (IPCC, 2007) and by UNDP as *a process by which strategies to moderate, cope with and take advantage of the consequences of climatic events are enhanced, developed, and implemented* (UNDP, 2005). The European Commission Adaptation White Paper (2009) states that *adaptation aims at reducing the risk and damage from current and future harmful impacts cost-effectively or exploiting potential benefits*. In addition the IPCC defines 'adaptive capacity' as *the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences* and 'resilience' as *the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change*. Finally the IPCC define 'capacity building' as *developing the technical skills and institutional capabilities in countries to enable their participation in all aspects of adaptation to, mitigation of, and research on climate change.*

([6]) It can sometimes be challenging to allocate adaptation options and actions to one specific cluster as adaptation responses often are a combination of measures and therefore are bound to include to some extent 'grey', 'green' or 'soft' elements.

strengthening of coastal and river flood defences/dykes, and beach 'nourishment';

- 'Green' actions: ecosystem-based approaches that use the multiple services of nature. Examples include crop diversification; reinforcing natural defences such as dunes or wetlands; maintaining and restoring healthy ecosystems; and enhancing the ability of indigenous plant and animal species to move across landscapes without interruption by man-made obstacles. Green adaptation actions seek to use nature to conserve or enhance carbon stocks, and reduce carbon emissions caused by ecosystem degradation and loss. When green adaptation actions are integrated into a spatially organised plan, they are known as 'green infrastructure'.

- 'Soft' actions: managerial, legal and policy approaches that alter human behaviour and styles of governance. Examples include: planning and passing legislation; water supply and demand management to mitigate drought and water scarcity risks; early warning systems for heat wave risks; natural hazards monitoring; landuse management and spatial planning; economic diversification and insurance; awareness raising and public information campaigns about health, and heat wave and cold spell risks.

'Green' and 'soft' actions specifically aim at decreasing the sensitivity and increasing the adaptive capacity of human and natural systems to build resilience. These actions are often less resource-intensive and provide multiple benefits. Hightech and innovative technological solutions typically need more funding, and require more research, experience and training to be implemented.

These three types of adaptation action can be further categorised according to the extent to which they are justifiable under different climate change scenarios. For example, a 'low-regret' adaptation action is one that would be justifiable under all plausible future scenarios of climate change, whereas a solution that would only make sense under very few climate change scenarios would be a high-regret option ([7]). 'Low-regret actions' are therefore of particular interest to policymakers. 'Low-regret actions' can be 'soft', 'green' or 'grey' actions, e.g. revising building or refurbishment codes for higher building insulation standards.

Another way of analysing the types of adaptation actions is by looking at the different decision-making processes that lead to their implementation. Planned adaptation aims at taking measures to counteract current or expected impacts of climate change within the context of ongoing and expected societal change. It is the result of a deliberate decision, based on an awareness that conditions have changed (reactive adaptation) or are about to change (anticipatory adaptation) and that action is required to return to, maintain, or achieve a desired state.

Autonomous adaptation is a spontaneous response in natural or human systems to a variety of factors, including climatic stimuli, socio-economic developments, and market forces. The focus in this report is on planned adaptation, even though it is challenging in practice to disentangle and systematically distinguish the various types of adaptation, since planned adaptation packages may also facilitate autonomous adaptation.

Adaptation and disaster risk reduction share the same ultimate goal: reducing vulnerability to hazardous events (IPCC, 2011). There are synergies to be exploited in closely coordinating disaster risk reduction and adaptation policies. Risk reduction and prevention in the short- and medium-term will primarily address socio-economic developments and climate variability to reduce the impacts of natural and technical hazards, while adaptation aims at developing longer-term planning to address climate change impacts. Preparedness refers to the readiness of human and natural systems to undergo gradual change through flexibility in practices and governance, and is a key common element of adaptation and disaster risk reduction actions.

There is also a need to better understand maladaptation, which occurs when specific adaptation actions (1) do not increase resilience/adaptive capacity or do not reduce vulnerability; (2) are not sustainable from an environmental, economic or social perspective (e.g. over-exploitation of water resources); or (3) conflict with other long-term policy objectives, such as climate change mitigation targets (EEA, 2009; IPCC, 2007). Maladaptation can be avoided by considering both the climatic and the socio-economic elements that constitute vulnerability to climate change.

([7]) Since any decision we take implies opportunity costs, we refrain from referring to 'no-regret actions' and use instead the more precise terminology of 'low-regret actions'.

There are limits to adaptation in terms of the time the action can be implemented in, and in terms of the geographical space in which the action will be helpful. There are also inherent limits to the extent to which any action will enhance adaptive capacity and fully protect regions, economic sectors, and communities. Authorities face the challenge of deciding which protection level to implement given their current and expected knowledge of climate change impacts and related damage costs, and of coping with the consequences that stem from the limitations of those measures. Cost/benefit analysis as well as assessments of probabilities and risks can inform the choice of protection level (e.g. whether to protect against a 1-in-100-year extreme weather event or a 1-in-1 000-year extreme weather event). Even when adaptation measures have been implemented, there will still be residual risks of vulnerability and impacts from climate change. These residual risks mean that policymakers will also have to devote adequate attention to disaster risk reduction.

1.3 The policy context for adaptation in Europe

There are several different contexts in which adaptation is being addressed. The scientific context of adaptation is primarily being developed within the IPCC's upcoming 5th Assessment Report, while work is also being done on the technological context. Other researchers are examining the role that 'natural capital' ([8]) and the Green Economy can play in adaptation. Although these contexts are all vital components of adaptation, the focus of this section will be on the policy context of adaptation.

Climate change is now recognised as a key challenge that policymakers must address through both mitigation and adaptation. However, while mitigation policy can call on a large body of integrated response options that have already been implemented, adaptation lacks an overall integrated approach that similarly embraces the related issues of governance, evidence and knowledge base, and appropriate policy tools.

There is now a clear demand from the European Environment Agency's stakeholders (the European Commission, the European Parliament and the EEA's member countries) to study the adaptation policy response to support them further in this field of work. The present report builds upon previous work done on climate change impacts and vulnerability (EEA, 2009, 2010, 2012a and 2012b), and extends it by addressing the adaptation policy response.

The current policy context is different from the one that prevailed before the Adaptation White Paper was published in 2009 (EC, 2009a) and created the framework for the development of the EU Strategy on Adaptation to Climate Change. Adaptation is a challenge that cuts across all economic sectors, and affects all geographical scales from the local level to the regional level, all the way up to the national and European levels. It therefore requires a response across all levels of governance from the municipal level all the way up to the European level. Because of this complexity, formulating the policy response means entering a field where knowledge, governance, policy tools and actions will have to be tailor-made to address the specificities of the related regions, sectors or communities. Guidance can be drawn from pre-existing adaptation policy in different parts of Europe as well as from examples of adaptation actions that have already been implemented. This can support policymaking and foster more coherent implementation across Europe and through the various governance levels. Factors that can promote or hinder adaptation also need to be analysed to support capacity building and adaptive management. The formulation of any adaptation response therefore requires a consideration of the necessary action itself, as well as a consideration of governance structures and tools that would support the implementation of the action (e.g. mainstreaming in existing EU policies).

In addition to EU policy that explicitly addresses adaptation, adaptation is also considered in other key EU initiatives, particularly 'Europe 2020 – Europe's growth strategy'; the Resource Efficiency flagship initiative; and the European Commission's proposal for a 7th Environment Action Programme to 2020 (EC, 2012). These provide policymakers and businesses with a long-term plan for how Europe will make the transition to a sustainable, low-carbon, resource-efficient, green and climate-resilient economy, where ecological resilience has been achieved (see Box 1.1).

The EU — and the world — must adapt effectively to a variable and changing environment and climate

([8]) Natural capital is 'an extension of the economic notion of capital (manufactured means of production) to environmental 'goods and services'. It refers to a stock (e.g. a forest) which produces a flow of goods (e.g. new trees) and services (e.g. carbon sequestration, erosion control, habitat).'

over the next century. The success of many local and community-based adaptation and disaster risk reduction initiatives suggests that adaptation measures require a context-dependent approach that takes into account the specificities of every situation. Adaptation measures must also be coherent, flexible and participatory, involving all stakeholders in the decision and implementation process approaches.

Adaptation policy design is an analytical ('what'), temporal ('when'), spatial ('where') and decision-level ('who', 'how') challenge (Fankhauser and Soare, 2013). There is a need to assess the location of current and future impacts together with the people, resources, and sectors at risk in order to gather information about the timeframe of these impacts and eventually take response actions. These response actions must implement adaptation at appropriate levels of decision-making and at scales that are appropriate for each of the climate change effects (see Box 1.2; see also Winograd (2009) for an illustration of ecosystem-based adaptation). Adaptation processes will first need to identify the specific risk factors for people, nature, infrastructure and resources. These risk factors are a combination of climate variability, climate change, and socio-economic contexts.

Adaptation therefore poses a multi-dimensional challenge in terms of identifying the regions, communities, economic sectors, and natural functions most vulnerable. Once this identification has been made, further work needs to be done to identify the goals and targets of the adaptation action and the most appropriate scales for action. This multi-dimensional challenge therefore requires coordinating and integrating policy mechanisms, so that short- and long-term strategies and instruments for planning and securing financial support are identified. For instance, adaptation efforts will need to be tailored to address a series of EU policies (e.g. sectoral, thematic, both short- and long-term), while at the same time being framed within national policies, and also taking into consideration the local conditions and needs since climate impacts vary geographically in magnitude and type. Thus, EU actions will need to take different forms based on: the resources available in different areas; the ability of communities to respond effectively; the nature of the current and projected impacts; the financial resources available; and the governance structure.

The use of EU policy 'levers' to support adaptation must take into account the specific requirements of the adaptation measure and the governance levels at which the measure will be implemented. This is necessary for three main processes. Firstly, it helps in mainstreaming adaptation in EU policies, e.g. implementing further ecosystem-based adaptation and market-based instruments. Secondly, it ensures policy and planning coherence in different governance contexts and for different sectoral and spatial scales (EEA, 2010b; Ahtonen et al., 2012; see also Section 4.1). Thirdly, it ensures the production and communication of appropriate and usable information for decision support. Thus adaptation at EU level means not only responding to anticipated impacts and increasing the resilience of vulnerable communities, it also means ensuring that decision-makers have proper tools to make informed, appropriate and proportionate decisions. This will drive the development and use of assessment tools and their capabilities in supporting EU decision-making.

As the implementation of adaptation measures progress and the first lessons are learned, there will be greater clarity concerning the requirements of future adaptation actions. There will also be greater clarity about how to further develop tools for sharing adaptation information and supporting decision-making at the European, national, regional and local levels. This iterative approach to adaptation is therefore quite different from those that prevail for point-source environmental problems, which often rely on more direct analytical frameworks ([9]).

This illustrates the multi-faceted nature of adaptation and how technological, scientific and governance issues are all inter-related. Adaptation is about managing change (within the context of societal change that has a degree of autonomy from the environment) rather than simply protecting a certain state or restoring it. Adaptation is a transition process made up of incremental and discrete changes that will benefit from an integrated approach in terms of the evidence it is based on, and the governance and supporting tools used in its implementation.

([9]) 'Point source' environmental problems refer to pollution or pollutants that come from a stationary location or fixed facility. For example, a power plant or sewage facility that emits pollution that could be mitigated by putting in place stricter pollution controls at the facility. By contrast, 'diffuse' pollution comes from multiple sources that are more difficult to control, such as nitrates in soil and rivers.

Box 1.1 Ensuring ecosystem resilience to support sustained prosperity

Ecosystem resilience can be defined as the capacity of an ecosystem to tolerate disturbance without collapsing into a (qualitatively) different state — the ability to withstand shocks or adapt when necessary. Human activities that adversely affect ecosystem resilience include those that lead to climate change, biodiversity loss, exploitation of natural resources, and pollution — or, more broadly speaking, the over-use of natural resources to fuel the economy.

Depletion of natural capital in Europe and elsewhere may jeopardise good ecological status and resilience. This can occur as a result of reduced natural resources, or disruption of the relationship between the ecological components required to maintain stable environmental conditions. The impact of climate change and the adaptation of ecosystems to these changes create additional uncertainty and risk. At the global scale, this risk has given rise to a discussion about global tipping points, and related environmental thresholds or planetary boundaries to avoid catastrophic environmental change.

The concept of ecosystem resilience is directly related to the notion of 'coping capacity' or 'adaptive capacity'. In environmental systems, adaptive capacity depends on factors such as genetic diversity, biological diversity and heterogeneity of landscapes. A society's adaptive capacity likewise depends on its readiness to respond to periods of change, relying on, for example, learning capacity, technological change and social fairness.

Resilience is thus also central to social systems, especially during transition processes, as it describes the degree to which societies can build capacity for learning and adaptation. This, in turn, is directly related to the ability for self-organisation in the pursuit of long-term objectives — whether environmental, economic or social goals. Building resilience at all levels, for example through sound social safety nets, disaster risk reduction and adaptation planning, is key in any effort to achieve global sustainability.

What do we mean by 'resilience'?

Simply put, resilience describes the stability of a system. In an ecosystem context, this has primarily been interpreted in two ways, reflecting different aspects of ecosystem stability.

On one hand, resilience describes the time it takes for an ecosystem to recover to a quasi-equilibrium state following disturbance (this can be referred to as 'engineering resilience' or 'elasticity'). On the other hand, resilience denotes the capacity of ecosystems to absorb disturbance without collapsing into a qualitatively different state that is controlled by a different set of ecological processes (this can be referred to as 'ecological resilience').

In practice, ecosystem resilience builds on three characteristics: an ecosystem's capacity to resist change, the amount of change an ecosystem can undergo and still retain the same controls on structure and function, and an ecosystem's ability to reorganise following disturbance.

Resilience thus relates to characteristics that underpin the capacity of socio-ecological systems to provide ecosystem services. There is a growing recognition that diversity plays an important part in the sustainable functioning of ecosystems. However, as resilience in ecological systems is not easily observed there is often no agreed understanding of their exact relationship.

Resilience is used analogously in social sciences and economics. In social systems, resilience is also affected by the capacity of humans to anticipate and plan for the future. Similarly, in economics, resilience also refers to the inherent and adaptive responses to hazards that enable individuals and communities to avoid potential losses.

Source: EEA, 2012d.

Box 1.2 Overview of key adaptation features

Adaptation is complex due to the fact that climate change affects all regions differently, most sectors, all levels of decision-making, and many actors with different backgrounds. Thus it often has implications beyond current planning practices (Grothmann, 2011; Prutsch et al., 2010).

- Inter-regional feature — Climate impacts and vulnerabilities emerge in many ways at the regional and local levels (Adger et al., 2007; Frankhauser, 2009; Swart et al., 2009). Due to the diversity of bio-physical and socio-economic situations in European regions, the impacts of climate change will differ from region to region. The impacts of climate change vary also according to the degree of socio-economic development and the adaptive capacity of the area. Thus, the consideration of regional climate change impacts and regional adaptive capacities are of crucial importance. Furthermore, different regions are interconnected. Therefore, adaptation to climate change is an inter-regional issue. For example, if a region in the European Alps reacts to water scarcity by extracting more water from its river(s) this has consequences for downstream water users. This challenge calls for inter-regional coordination of adaptation policies. For example, the Alpine Convention, by addressing both conservation and development issues, supports transnational cooperation and the development of common frameworks through a series of initiatives, including its Natural Hazards Platform (PLANALP) ([10]).
- Cross-sectoral feature — Adaptation to climate change affects most economic sectors and thus is a multi-sectoral issue (Burton et al., 2006; Agrawala and Frankhauser, 2008). Since different sectors are interlinked adaptation is also a cross-sectoral issue. For example, a shift from ski tourism (including artificial snow-making) to all-year tourism may impact not only the regional tourism economy, but can also affect other sectors such as energy, water or nature conservation. The sectors involved might follow different objectives and a certain adaptation measure in one sector could create negative side effects for another sector. In addition, adaptation involves actors from different sectors, representing a diversity of values and interests that might be controversial and generate resistance (de Bruin et al., 2009). This challenge calls for a better 'horizontal' integration of adaptation policies across sectors within and beyond the environmental domain. It also requires mechanisms that facilitate the interaction between state, business and civil society actors in the respective sectors.
- Multi-level feature — The 'sphere of competence of authorities in charge of environmental protection […] does not always match with the boundaries of the affected environment' (Liberatore, 1997). The same also applies for authorities in charge of adaptation, because adaptation pressures and responses cut vertically across different levels of decision-making from the EU to the national level, and from the national level to the provincial and local levels (Klein et al., 2007). These different levels and actors interact with each other within hierarchical structures (Adger and Vincent, 2005). For example, in water management, the European Commission has established the Water Framework Directive with the obligation to protect and restore the quality of waters across Europe (EC, 2010) and has issued a guidance document on adaptation to climate change in water management (EC, 2009b). The Member States have transposed the directive into national legislation, thus defining river basin management in their national contexts. This is the level at which programmes and measures, including adaptation initiatives, will be implemented. This example demonstrates that the need for appropriate adaptation extends beyond the local and regional scale: adaptation is an issue relevant at all levels of governance (Adger and Vincent, 2005; Paavola and Adger, 2006; Swart et al., 2009) and cannot be the sole responsibility of any single institution (UNDP, 2010).
- Multi-actor feature — Climate change will affect (and already does today) a range of actors and stakeholders (e.g. citizens, public authorities, scientists, businesses, NGOs) in different ways and thus makes active engagement in adaptation imperative for most actors. Therefore joint-up actions, exchange of knowledge and expertise and mutual learning between different actors from government, business and civil society are — among others — effective means to address complex and uncertain problems (Grothmann, 2011; Lebel et al., 2010). These mutual learning processes raise questions about the role, power, authority and responsibility (Biesbroek et al., 2010), as well as the multiple interests of actors working together in adaptation (Preston et al., 2010). New mechanisms are probably needed to allow learning and cooperation between actors and stakeholders from different fields and with different competencies.

([10]) http://www.alpconv.org/en/organization/groups/WGHazards/default.html and http://www.planat.ch/de/partner/planalp/. See also the recommendations on Integral Natural Hazard Risk Management at: http://www.alpconv.org/en/organization/groups/WGHazards/Documents/PLANALP_Hotspot_Paper.pdf.

1.4 Socio-economic developments: adaptation beyond climate change

The vulnerability of a region, sector or population is a function of the expected change it will undergo as a result of both climate change and societal change.

Socio-economic developments (such as greater wealth, or having more assets in risk-prone areas) play a significant and sometimes dominant role in the exposure and vulnerabilities of regions, economic sectors, populations or nature. They can outweigh or alter the effects of climate change, particularly in the short and medium terms. This is the reason why it is important to take into account societal change in both adaptation planning and disaster risk prevention.

Any driving force falling under the social, technological, economic, environmental or political realm (referred to as the 'STEEP' model) determines the socio-economic context within which climate change will unfold in future. These STEEP factors can therefore be a key driver of change for climate change-related risks and vulnerabilities. Key socio-economic variables include: economic wealth and commodity prices; developments in individual economic sectors and technological innovation; demographic dynamics (e.g. growth, ageing, spatial distribution); consumption patterns and lifestyles; settlement patterns (e.g. urban growth and sprawl); infrastructure developments; and land cover and land use. Strong inter-linkages and feedback loops exist between the different drivers of socio-economic change and it is important for the quality of scenario studies that these drivers are taken into account in a consistent manner.

Integrated exercises assessing future consequences of climate change use tools and methods that incorporate assumptions and scenarios for both socio-economic developments and climate change variables (e.g. temperature, precipitation). Although the socio-economic variables are usually clearly differentiated from the climate change variables in terms of data inputs or assumptions, the majority of studies report their combined effect. There is no 'attribution' made to the role played by individual causes.

Up until recently many integrated and modelled climate change exercises (presented below or elsewhere) were based on the so-called SRES scenarios (Special Report on Emissions Scenarios, Nakicenovic and Swart, 2000) as they provide both projected climate change and socio-economic scenarios in a coherent and consistent manner.

The storylines developed for the SRES scenarios have been formulated so as to be internally consistent, and the scenarios are available for four world regions. This has therefore provided a solid background used as a reference for most climate change impact and vulnerability/risk related assessments for Europe over the last 10 years.

The SRES socio-economic scenarios have become a reference the same way the SRES projected climate change variables have. The findings of the projects presented in EEA (2012c) use a range of SRES (socio-economic and climate) scenarios, i.e. the 'A1B' scenario for the urban flooding assessment and the ESPON-Climate integrated project; the 'A2' and 'B1' scenarios for the DIVA-based coastal flooding exercise; and the 'A2' and 'B2' scenarios for assessing river flood damages. In addition, assessments of future climate change costs of inaction and of adaptation also often rely on the SRES scenarios (EEA, 2010b).

The next generation of scenarios for climate change research and assessment will feature in the IPCC's 5th Assessment Report, due out in 2014. Moss et al. (2010) describe in detail the process by which these scenarios are being developed to take advantage of the latest scientific advances on the response of the Earth's environment to changes in radiative forcings — the difference between energy received by the earth and energy radiated back to space. The scenarios also include new findings about how societies evolve through changes in technology, economies, lifestyle and policy. The research community took up the task of developing new scenarios by departing from the sequential approach of the previous set of SRES scenarios from the IPCC. Their approach includes the parallel development of new climate scenarios (based on the four representative concentration pathways or RCPs, which sketch out different hypothetical levels of greenhouse gas concentration in the atmosphere; van Vuuren et al. (2011)) and new socio-economic scenarios (the so-called 'shared socio-economic pathways', or SSPs) with a more regional approach to explore important socio-economic uncertainties affecting both adaptation and mitigation. The integration of these two sets of scenarios will be made in a final stage (2013/2014) to provide insights into the costs, benefits and risks of different climate futures, policies and socio-economic development pathways. The new scenarios assume there are policy actions to mitigate climate change, and are expected to factor in the economic recession. The time frames of these scenarios (typically climate change and socio-economic development by 2100)

differ from the ones usually considered in the planning of adaptation (typically 2020 and 2050) and this will need to be addressed to facilitate the use of the scenario work into policymaking.

The five shared socio-economic pathways reflect different projections for the socio-economic future of the 21st century, based on key socio-economic variables such as: population and human resources; economic development; human development; technology; lifestyles; environmental protection and natural resources management; and policies and institutions (O'Neill et al., 2011). The conceptual framework used for the development of the SSPs is described in depth in Kriegler et al. (2012) and van Vuuren et al. (2012). So far the SSPs have been underpinned with quantitative projections of demographics (age, sex, and education), economic development (GDP) and urbanisation (see examples in Figure 1.1). It is important to note that all the SSPs envisage an increase in wealth per capital in Europe by 2100.

Until new results in relation to the IPCC 5th Assessment Report become available, the availability of EU-wide (and disaggregated at sub-national levels) future scenarios for key socio-economic variables is still limited. It is particularly challenging to develop systematic and consistent methodologies that can deliver information that is suitable for integration with projected climate change variables.

Recently, alternative socio-economic scenarios have been developed, at both the European scale and globally, in connection with the IPCC's 5th Assessment Report. One example is the scenario set developed in Europe in connection with the study 'Climate adaptation — modelling water scenarios and sectoral impacts' (ClimWatAdapt project, European Commission — DG ENV). The ClimWatAdapt project (http://www.climwatadapt.eu) and its predecessor SCENES used an iterative participatory process to develop both qualitative and quantitative scenarios of Europe's freshwater up to 2050.

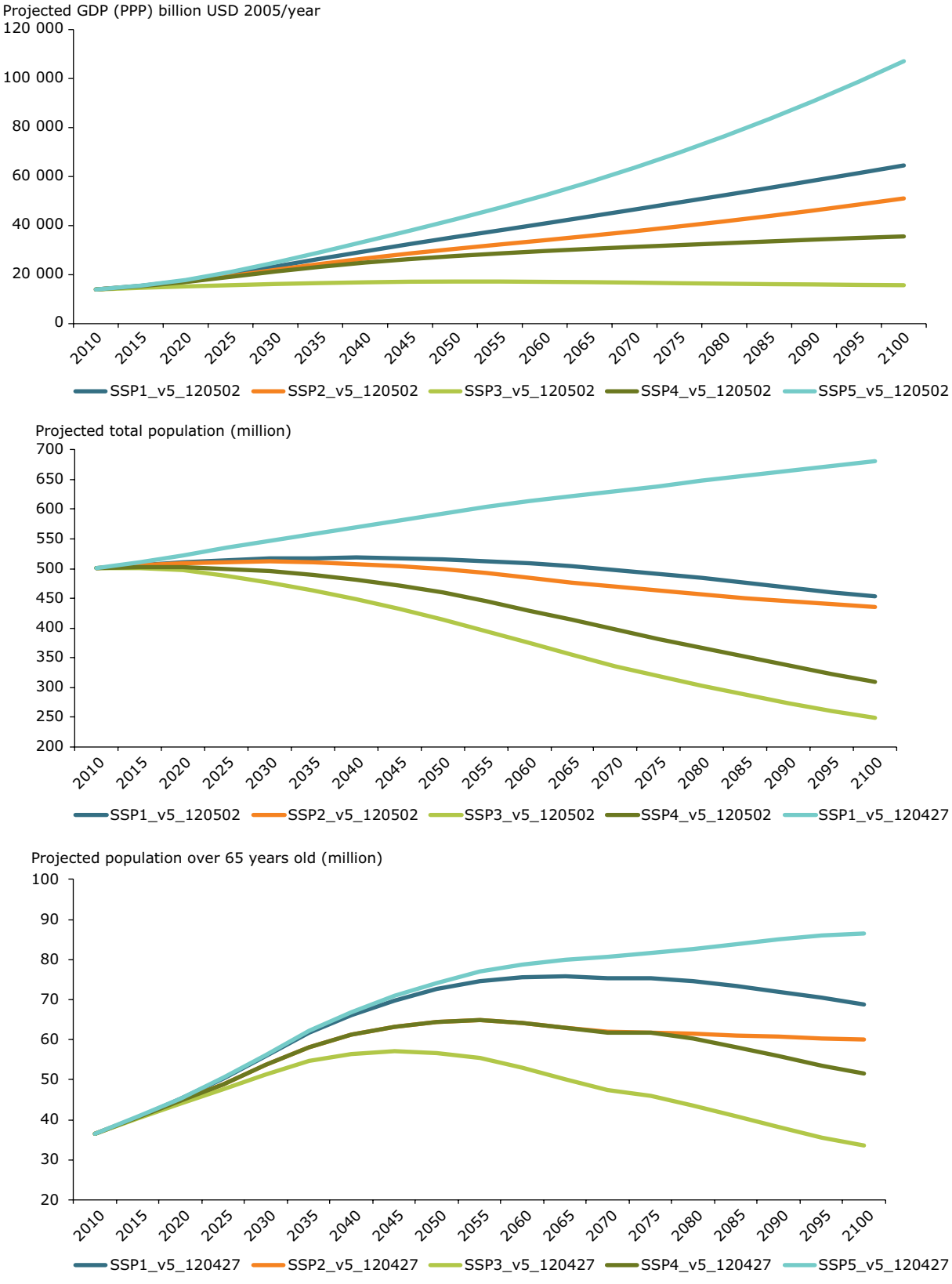
The ESPON-DEMIFER (Demographic and Migratory Flows Affecting European Regions and Cities) project recently provided population projections for Europe (disaggregated at the 'NUTS2' sub-national level) until 2050, which provide an update for a key socio-economic variable (Joop De Beer et al., 2010). Other initiatives specifically addressed the economic and social consequences of demographic change on regional and urban development (Hungarian Presidency, 2011), or linked European socio-economic developments to global trends along the social, technological, economic, environmental, and political dimensions (EEA, 2010c).

A recent report by the European Commission (EC, 2011b) provides some relevant demographic and economic projections (for example on fertility rates, life expectancy, EU population, ageing and migration, labour supply, and economic growth) and highlights the wide diversity within and across countries.

There is a large variety of socio-economic scenario studies available in the field of climate change research and policy development. This reflects both the specific needs of the mitigation and adaptation communities (e.g. researchers, policymakers or those implementing policy), and the fact that forward-looking studies are associated with significant uncertainty about future socio-economic developments and their impact on humans and ecosystems. There is a need to enhance consistency and comparability in the use of socio-economic scenarios for climate change risk assessments across Europe.

Despite the large variety of scenarios available or being produced, there remains the possibility of surprise 'wild cards', particularly in the socio-economic realm. However, the availability of a wide range of scenarios can still help identify options for robust approaches to adaptation.

Figure 1.1 Socio-economic projections for the European Union (EU-27; SSPs)



Note: Top: Projected GDP (PPP); middle: Projected total population; bottom: Projected population over 65 years old.

Source: IIASA, 2012. SSPs: Shared Socio-economic Pathways.

2 Adaptation in practice

Key messages

- Adaptation measures are already being implemented across Europe. Because different regions have different vulnerabilities to climate change and different socio-economic characteristics, an adaptation measure that is suited to one place may not be applicable in another. Nevertheless, examples of adaptation measures are still useful in helping policymakers see how action has been successfully implemented in a variety of different places, so they can learn from previous experiences.
- To reduce vulnerability to climate change and create resilience, 'grey' adaptation actions use civil engineering projects. Examples include dyke building and beach restoration to prevent coastal erosion.
- 'Green' adaptation actions make use of nature. Examples include introducing new crop and tree varieties, allowing room for rivers to naturally flood onto floodplains, and restoring wetlands.
- 'Soft' adaptation actions are managerial, legal and policy approaches that alter human behaviour and styles of governance. Examples include early warning systems that can monitor threats from heatwaves, floods and new disease types, or financial infrastructure that can insure against damage from natural disasters.
- It is important to note that these three types of actions are not restricted to any one policy area. In fact, the best results are often achieved by combining actions. For example, flood risk in a particular area can be addressed by a combination of green and grey actions, or grey and soft actions.
- The European Commission and the EEA have assembled an online library of adaptation case studies at the European Climate Adaptation Platform (Climate-ADAPT, http://climate-adapt.eea.europa.eu). EU Framework Programme (FP) projects, INTERREG projects, and ESPON projects also contribute to developing EU-wide information on the implementation of adaptation actions.

This chapter provides a series of concrete examples that illustrate adaptation in practice across Europe, and the policies and tools that foster its implementation. It therefore allows policymakers a better understanding of the factors of successful adaptation policy, and how they can best avoid the obstacles that prevent implementation of adaptation policy.

2.1 Overview of examples

There is a wide range of measures that have been taken across Europe to adapt to climate change. The establishment of the European Climate Adaptation Platform (Climate-ADAPT) has begun to gather adaptation case studies of European relevance, providing an overview of this diversity of measures to all stakeholders with an interest in adaptation.

One of the purposes of this report is to draw attention to a series of examples that are illustrative of either climate change and socio-economic challenges, or of the role the EU has played in the adaptation action. In this chapter, we provide only a few examples of adaptation measures. We have limited the number of examples we present and the detail we present them in for two main reasons: (1) developing a comprehensive overview of recent and relevant actions is an on-going task and no list could ever be fully complete; and (2) the Climate-ADAPT platform, together with national adaptation portals, are the appropriate information-sharing tool for documenting case studies in a more comprehensive manner.

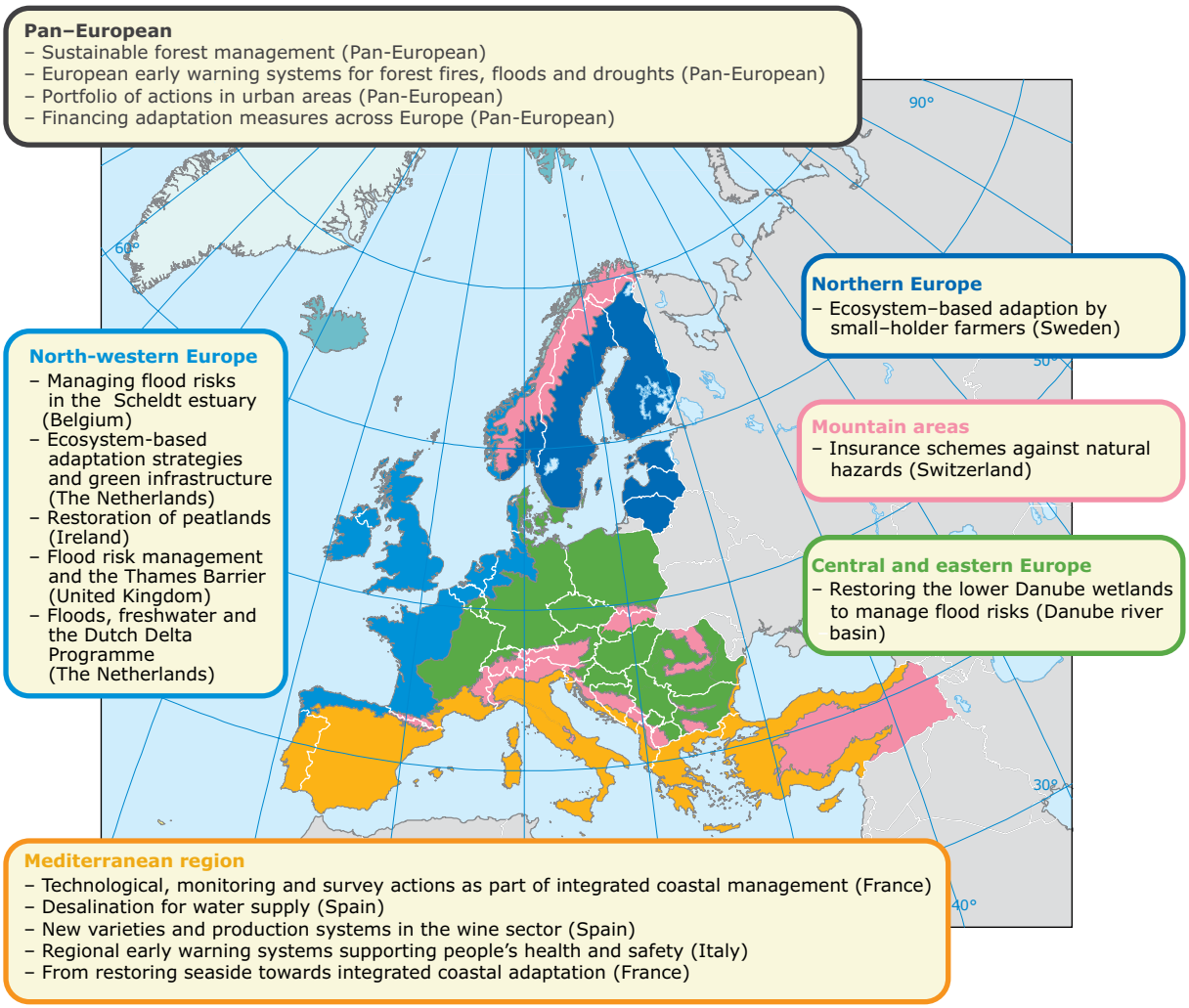
The examples reported in this chapter accomplish three main goals. Firstly, they illustrate the nature and size of the adaptation challenge. This challenge

covers a diversity of threats and opportunities that stem from climate change and socio-economic developments. These threats and opportunities affect vulnerable regions, sectors, and communities. Secondly, the examples illustrate the type and range of actions, covering the 'grey', 'green', 'soft' and combined/integrated options. Thirdly, they illustrate adaptation across the various governance levels (i.e. European, national, regional and local).

Map 2.1 depicts the geographical and thematic coverage of the examples reported in this chapter. Table A1.1 in Annex 1 classifies the examples in this chapter according to the main types of adaptation actions they use (i.e. 'grey', 'green' and 'soft'), and also details other characteristics of these actions. Table A1.1 also provides many additional information sources for adaptation examples and case studies, which complement the limited overview reported in this chapter. Some of these are available on Climate-ADAPT (see the Case Study Search Tool, http://climate-adapt.eea.europa.eu/web/guest/sat) and the transnational section, http://climate-adapt.eea.europa.eu/web/guest/transnational-regions).

EU funds are a key vehicle for 'climate-proofing' investments, i.e. investing to make societies resilient to climate change. 'Climate proofing' is also increasingly dependent on implementing ecosystems-based measures within a 'green infrastructure' approach. Spatial planning is a key component of this green infrastructure approach. For example, spatial planning can be used to make cities and coastal zones more resilient by making room for green areas like parks or wetlands within cities in order to reduce urban temperatures and manage floods or water scarcity.

Map 2.1 Overview of examples



Faced with the considerable economic impact of climate change and the partial solution offered by insurance, businesses face uncertain and unstable revenues (and potential considerable financial losses) over the lifetime of their investments. Adapting our physical infrastructure to cope with the challenge of climate change is not simply a question of physical and ecological engineering. It also requires the adaptation of our financial infrastructure and investment decision-making so they are better able to foster the investment needed to make our societies more resilient.

Climate-proofing investment is already a key priority of the EU. One of the most important vehicles for this climate-proofing is the EU Cohesion Fund. These Cohesion funds represent significant sums of money, so mainstreaming adaptation into them would have an important effect. One key instrument of the EU in this respect is the Multi-annual Financial Framework and the territorial cohesion policy. The proposal for the EU's Multi-annual Financial Framework 2014–2020 foresees using 20 % of the budget for climate change mitigation and adaptation stemming from different policy sectors.

There are a series of generic adaptation options that have already been identified and are ready for stakeholders to consider (see details in Section 1.2). Because each region is different and has different adaptation requirements, these generic options will have to be tailor-made before being implemented. However, generic adaptation options are still helpful in illustrating to 'practitioners' (people implementing adaptation policies on the ground), policymakers and other stakeholders the opportunities for action that exist.

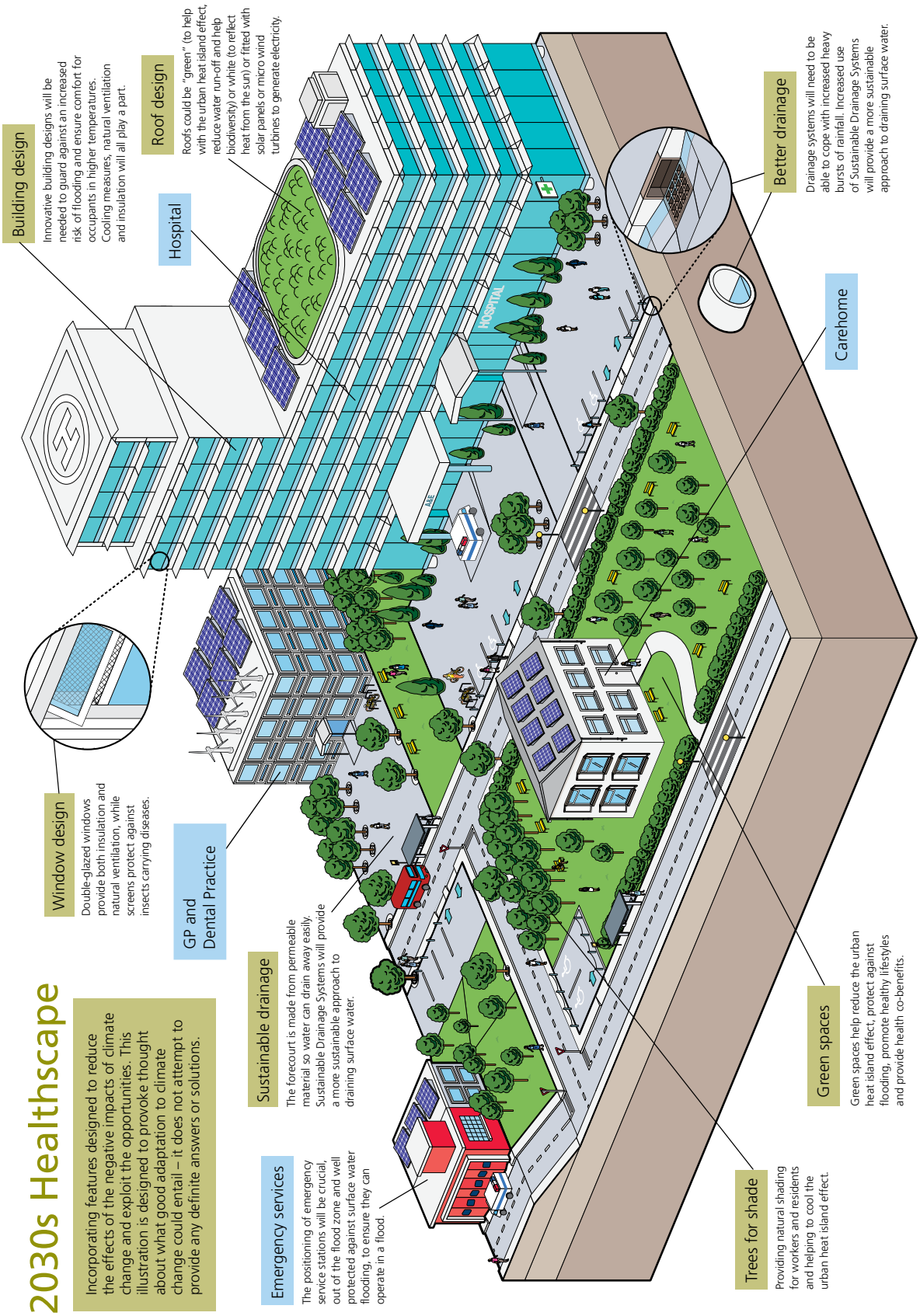
This chapter also introduces examples of 'combined adaptation actions'. These are illustrative examples that cut across integrated environmental systems, sectors and policy domains. They typically illustrate the necessary combination of grey, green and soft measures for achieving integrated goals, and also show the results that can be achieved by combining funding from European, national, regional and local sources. These examples can usefully support stakeholders in their current and future assessments of risk and adaptation.

One area where a combined adaptation action is likely to be necessary is in cities and coastal zones, which will need large amounts of investment over the coming years to adapt to climate change and other socio-economic developments. Measures that combine grey and green investments have the potential to deliver robust and flexible measures that will take care of the built, human and natural environments. These can be further supported by soft adaptation measures (e.g. information-sharing, new forms of governance) that are often relatively inexpensive and easy to implement.

Several packages of options have been developed so far for the purposes of illustration. Figure 2.1 includes one of the seven 'Future Worlds images' developed by the UK's Department for Energy, Food and Rural Affairs (2012c). The images show potential ways to adapt to climate change in both urban and natural environments, based on an understanding of what the climate will be like in 2030 in the United Kingdom. They do not attempt to provide definitive solutions as the most appropriate action will depend on local circumstances. The illustrations are designed to give an indication of what adaptation solutions might look like, and do not necessarily illustrate past, present or future government policy. Instead, it is intended that they should act as a pointer to some of the issues that citizens, farmers, policymakers and business people need to start thinking about in order to take advantage of the opportunities and minimise the risks from long-term climate change. Figure 2.1 also includes one graphic on managing flood risks extracted from Shaw (2007), which illustrates a menu of adaptation options using practical examples. The graphic is organised according to the main climate risks that communities in the United Kingdom will face at different spatial scales (conurbation or catchment; neighbourhood; and individual building level).

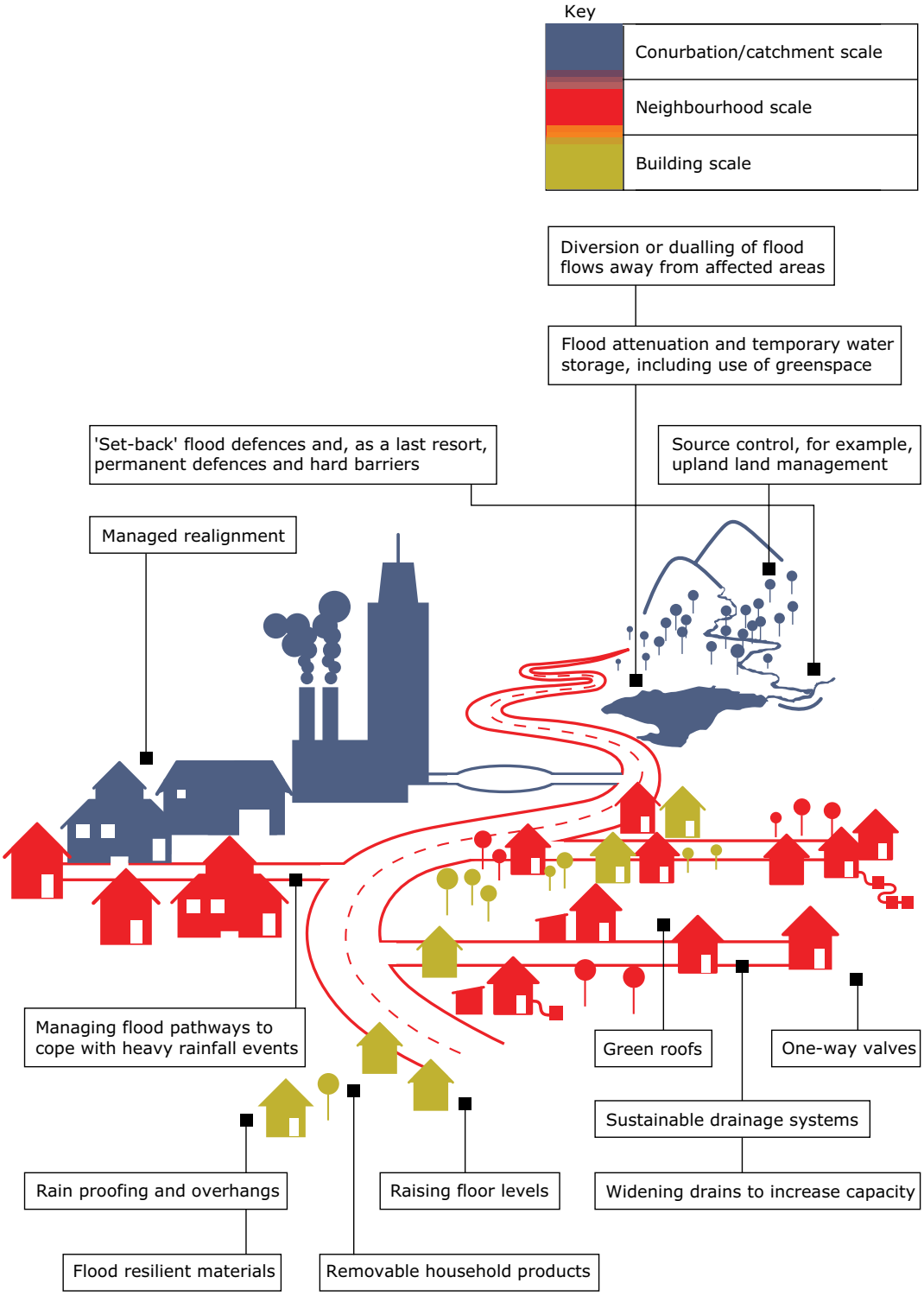
The examples of implemented actions given in the following sections address many environmental, climatic and socio-economic issues by straddling different policy sectors and bringing different levels of governance together. In so doing, they illustrate the challenges but also the opportunities of adaptation. It is critical to remind the reader that this report does not aim at being exhaustive. Examples presented in this chapter show policymakers, decision-makers and practitioners that adaptation is already a reality across Europe, and that adaptation covers a wide range of measures across natural and human systems.

Figure 2.1 Menus of generic adaptation options



Source: DEFRA, 2012c.

Figure 2.1 Menus of generic adaptation options (cont.)



Note: The diagram summarises the range of actions and techniques available to increase adaptive capacity.

Source: Shaw, 2007 (Courtesy of the TCPA). Graphic by thomas.matthews (www.thomasmatthews.com).

2.2 Grey adaptation actions

2.2.1 Technological, monitoring, and survey actions as part of integrated coastal management (France)

Adaptation goals
(i) Restore and rehabilitate beaches and dunes by fighting coastal erosion; (ii) Attenuate the effects of coastal swell; (iii) Improve road traffic and transport along the coastal area.

Adaptation context
A range of adaptation options and responses are available for integrated coastal management. They include: building or strengthening coastal and river flood defences to address rising sea levels and accommodate transport at the coast; attenuating the effects of the swell by constructing submarine tubes, restoring the coastline by developing drains and installing storm monitoring devices; protecting and strengthening natural defences such as dunes, wetlands and other green infrastructure; and managing the use of land and retreating from the coast.

Adaptation actions
The goal for Le Lido beach from Sète to Marseillan on the Mediterranean coast (France) is to recreate the natural cycles of the beach and restore dune vegetation. Three main actions were taken. The first action was the displacement of the old road. Previous erosion had reduced the width between the water's edge and the road, and a new road was rebuilt further inland in order to maintain a beach width of 70 metres. The second action was the partial reconstruction of the dune, which was restored or rehabilitated over a length of about 20 km. Sand traps made of local wood were added to the dune to avoid the dispersion of sand and to help support new vegetation. The third action was the creation of a sand 'nourishment' programme, whereby additional sand is placed on the existing beach to compensate for erosion. In addition to these measures, test programmes were initiated on the stretch of coast east of Lido to study two innovative methods of protection against storms and probable sea level rises. The tests are examining two technological adaptation actions to attenuate the swell and: the 'Ecoplage' project (launched in March 2012) and the 'Geotube' project (from autumn 2012). The best feature or combination of both processes will be deployed on the most fragile area of the Lido beach. The final stage of the adaptation programme is a series of new research and development projects, such as regular surveys on topographic profiles, and monitoring of land erosion and storms using digital video cameras installed on poles about 6 m high.

Financing
During the last three years, EUR 200 m were invested in this project. The European Union, via FEDER funds, has contributed 20 % of the cost. France, via the government FNADT and CDEP funds, contributed 30 % of the cost, while the Languedoc-Roussillon region and Département de l'Hérault also contributed 30 %. The Thau Agglomération contributed the remaining 20 %.

Results/lessons learned
Three years after the start of the integrated management and construction, the concrete results of the protection programme are now visible. The new coastal road has been moved inland, against the railroad. On the sea side of the road, the dune has now been restored and protected and the beach now has an average width of up to 70 metres. Vegetation now grows in the sand traps.

This section of coast is now protected against storms and sea erosion. The landscape has been helped to return to its natural cycles to offer residents and visitors a renewed amenity for recreation, tourism and nature appreciation. The programme also contributed to the preservation of other inland activities such as viticulture.

Finally, the process has also led to new methods of policymaking, creating new collaborative relationships between politicians, administrations, citizens and other stakeholders at regional, national and European level (see also Section 2.5.1).

Sources
EEA, 2010b; Parc National de la Camargue: http://www.parc-camargue.fr; Thau agglomération: http://www.thau-agglo.fr/-Le-developpement-durable-.html; http://www.parc-camargue.fr/index.php?pagendx=1080#ref_1092.

2.2.2 Managing flood risks in the Scheldt estuary (Belgium)

Adaptation goals
The Sigma Plan aims to better protect Flanders against flooding by the Scheldt and its tributaries. At the same time, the plan aims to restore the nature of the Scheldt region.

Adaptation context
The Scheldt plays an important role as one of Europe's busiest navigable rivers. During a

disastrous storm tide in 1976, the Scheldt and its tributaries flooded large areas throughout Flanders. Antwerp (Ruisbroek) and a number of areas in eastern Flanders were seriously affected by the flooding. The human and material cost was enormous, and the government decided that greater protection against flooding was required. The programme of measures that resulted was named the Sigma Plan, which resembled aspects of the Dutch 'Delta Works' programme.

Adaptation actions
The Sigma Plan contained three initial measures to better protect Flanders from flooding:

- stronger and higher dykes;
- flood control areas to absorb excess water caused by storm tides or by abundant precipitation from the more elevated areas;
- a storm surge barrier in Oosterweel.

Construction of a storm surge barrier was suspended for an indefinite period early on. Analyses showed that the benefits of the barrier would not outweigh the costs.

Science has evolved since the plan was first formulated. Thus, today we know that the sea level will continue to rise as a result of climate change. Extreme weather conditions will also occur more frequently. Hence, the measures in the original Sigma Plan can no longer adequately guarantee safety. The understanding of water management has also evolved. A river needs space in which to flow and to flood. Safety can go hand in hand with protecting, managing and restoring natural environments. These principles are more clearly outlined in the updated Sigma Plan, which was released in 2005.

In accordance with the updated plan, the dykes along the Scheldt and its tributaries will be reinforced and raised. A chain of new flood control areas will give the river more room to flood. In addition to making the Scheldt safe, Flanders is committed to restoring the river's natural quality. This development of nature is vital to achieving Europe's nature objectives for Flanders.

The Sigma Plan aims to develop a sustainable Scheldt. This means development of all the functions of the river in a balanced way. Protection against floods is the first priority of the Sigma Plan. Restoration and development of the natural species and habitats of the Scheldt region is the second priority. As the project progresses, gradually all of Flanders will be better protected against floods. At the same time, flood control areas, wetlands and de-poldering will gradually open up new opportunities for nature.

The Sigma Plan also has other goals, such as improving the possibilities for recreation in and around the Scheldt. The Plan includes measures to allow holidaymakers to fully enjoy the natural splendour and the landscape along the water. The hotel and catering industry and the countryside economy will also benefit.

Another goal of the plan is to maintain the economic functions of the Scheldt region, such as shipping and the countryside economy. Finally, the Sigma Plan is developed in such a way that the disadvantages to agriculture are kept to a minimum.

The new Sigma Plan will contribute to a multifunctional and sustainably used Scheldt. It will help create a robust and powerful river that is able to fulfil all its functions for the foreseeable future.

Administrative interactions
The Sigma Plan was created by the Flemish government. The Flemish Waterway authority Waterwegen en Zeekanaal (W&Z) leads and coordinates the project. For the nature component, W&Z works closely with the Nature and Woodlands Agency (ANB).

The plan has also enjoyed cooperation from other partners. The Flemish Land Agency (VLM) assists in developing the supporting agricultural policy, while the Spatial Planning, Housing Policy and Built Heritage Department contributes to the spatial components of the Sigma Plan. The plan also actively involves local governments, agricultural organisations, nature associations, hunters, and fishermen, as well as the tourism, hotel, and catering industries.

Results/lessons learned
It took many years to complete the Sigma Plan. The construction plans stayed relatively flexible during this time so they could accommodate any new climate change impacts data. This shows the importance of flexibility and of ensuring that construction plans are continually updated with the latest climate science to provide the best information to implement adaptation solutions.

Sources
http://www.sigmaplan.be/en.

2.2.3 Desalination for water supply (Spain)

Adaptation goals
Respond to water scarcity and droughts by increasing water supply.

Adaptation context
Extended drought periods have in the past forced Barcelona to import drinking water by boat. Barcelona decided to address its water shortages by developing a desalination plant that would make the most of environmentally friendly technology. Desalination provides a weather-independent source of urban water for drinking and non-drinking purposes.

Desalination is increasingly being used within Europe and beyond. But the process is energy intensive, which makes it greatly attractive to use new technology that can either improve desalination efficiency or make use of renewable energy resources. The disposal of brine — a by-product of the desalination process — is also still a concern. These environmental and energy concerns mean that a decision on the suitability of future desalination plants needs to be made on a case-by-case basis accounting for all environmental and economic issues (EEA, 2009).

Within the 6th Framework Programme of the European Union, two projects were funded to improve desalination methods using solar and wind power. These are the MEDESOL (EU Seawater desalination by innovative solar-powered membrane-distillation system) and MEDINA (Membrane-Based Desalination: An Integrated Approach) projects.

Desalination is mentioned in the EU Communication 'Addressing the challenge of water scarcity and droughts in the European Union'. However, a Commission position on desalination will have to await further work on risk and impact assessment, taking into account the specific bio-geographical circumstances of Member States and regions. Some desalination plants have already been funded under the EU Regional Development Fund, such as the Alicante II desalination plant, which was completed in December 2008 and received ERDF co-financing of EUR 67.9 m, i.e. 75 % of its overall cost. A solar energy park has also been constructed to provide the plant with 797 kW of energy at peak capacity.

The communication on resource efficiency (COM(2011) 21), clearly aims to create a framework for policies to support the shift towards a resource-efficient and low-carbon economy.

Desalination is mentioned in this communication as an option that provides a solution to water supply problems, although it notes that desalination may also increase fossil fuel consumption and greenhouse gas emissions.

In Spain, the Ministry of Environment developed a desalination programme to fulfil the requirements of the Water Act (R.D. Ley 2/2004) within the framework of water scarcity management.

Adaptation actions
Barcelona constructed a 200 000 m^3/day desalination plant following an extended drought, which had forced the city to import drinking water via boat. Fully operational since July 2009, the plant satisfies 20 % of Barcelona's drinking water needs.

In 2010, the Barcelona Llobregat desalination plant was recognised as 'desalination plant of the year' at the 2010 Global Water Awards for its efforts to reduce the environmental harm of desalination. These efforts have included steps to decrease harmful environmental impacts by diluting brine with wastewater from the nearby Baix-Llobregat wastewater treatment plant before discharging it into the sea. Energy recovery was also boosted by applying PX Pressure Exchanger (PX) devices, enabling energy recycling at up to 98 % efficiency.

Financing
The EUR 230 m El Prat de Llobregat desalination plant, which can supply Barcelona with 200 000 m^3 per day of potable water, was developed by ATLL (Aigües Ter-Llobregat) in a Joint Venture between Degrémont, Aigues de Barcelona and Dragados-Drace. The project has received funds from Generalitat e Catalunya and Barcelona county as well financial assistance from the EU Cohesion Fund. In 2012, the plant was privatised and is now managed and operated by ACCIONA SA (Spain) and BTG Pactual (Brazil).

In general, the costs of desalination plants have decreased significantly but they are still dependent on plant size, raw water quality, energy costs, and terms of financing. In many cases, these costs are similar to incremental conventional bulk water supplies (e.g. moving water from nearby regions), which often involve inter-basin transfers.

Results/lessons learned
Non-conventional technological solutions, such as desalination plants, have to be carefully crafted and planned on a case-by-case basis in terms of their economic, social and environmental consequences (e.g. high energy use, the problem of brine disposal)

so that they are sustainable measures and not vectors of maladaptation.

Sources
EEA, 2012a; Flörke et al., 2012.

2.3 Green adaptation actions

2.3.1 Ecosystem-based adaptation by small-holder farmers (Sweden)

Adaptation goals
(i) Improve diversity, design and implementation of farming practices; (ii) Implement ecosystem-based adaptation measures by changing management practices.

Adaptation context
Small-holder farmers in Roslagen, in the east-central area of Sweden, face difficult climatic conditions, as they experience long winters and frequent periods of drought. The climatic uncertainty, combined with threats from pests and disease, presents challenges for sustaining livelihoods, with climate change predicted to increase the vulnerability even further. Following a series of mild winters in the 1990s that led to more severe pest outbreaks and the fungal infestation of crops, farmers in the Roslagen region undertook to incorporate a range of ecosystem-based practices to diversify, and increase resilience to uncertain conditions and disturbances. This included reintroducing the multiple-species farming methods common in the past (which had fallen out of practice), with the aim of producing a more reliable harvest during varying climatic conditions.

Adaptation actions
A range of ecosystem-based measures were incorporated to buffer the impacts of climate variability and increase overall resilience. These measures included planting different types of crops and at different times of the year in order to reduce the risk of crop failure, and in order to increase genetic diversity and test the pest resistance of different crops. Incorporating crop rotation helped to revitalise soils and prevent pest infestations, without reliance on chemical fertilisers and pesticides. Measures to cope with drought included: planting trees to provide shade; using 'cover crops' to enhance seedling survival; and harrowing fields in early spring to prevent evaporation. To aid flood control and water regulation, groups of trees in nearby wetlands were protected from felling. In addition, by establishing an informal local network, the farmers were able to share good practice and local ecological knowledge, helping them to carve out a niche in low-input agriculture, producing high-quality and organic products.

Results/lessons learned
Both new and old crop varieties were introduced to test their pest resistance. Farmers found that the multiple-species cropping systems common in the past could produce a more reliable harvest during varying climatic conditions. Such ecosystem-based practices enabled the small-holder Roslagen farmers to adapt to a dynamic environment. By diversifying and adjusting ecosystem management practices, farmers can produce high-quality and organic products, whilst increasing their resilience to climate variability and climate change. These practices also enhance biodiversity and economic security.

Sources
Tengo and Belfrage, 2004.

2.3.2 Ecosystem-based adaptation strategies and green infrastructure (the Netherlands)

Adaptation goals
Use ecosystems to manage water and improve natural resilience.

Adaptation context
In the past decade, researchers working for private institutes, NGOs and the Dutch government have realised the limitations of traditional 'hard' infrastructure in managing the country's water systems. In so doing, they have sought to respond to climate change threats in a more integrated way, using nature or ecosystem-based approaches, such as making use of the natural functions of coastal or river systems.

This has led to the development of a variety of 'green' and 'soft' adaptation measures in which natural functions play an essential role. All these measures are based on the same idea: making use of natural processes and ecosystem services in order to increase safety and enhance (or at least maintain) ecosystem functioning, while ideally reducing either the maintenance or construction costs of adaptation measures.

While these measures are specifically designed for the Dutch situation, the underlying principles behind these concepts are in many cases applicable in other countries at different stages of economic development. And lessons learned in Dutch pilot projects may be very valuable for developing climate adaptation plans outside the Netherlands.

Adaptation actions
Examples of newly developed green adaptation measures to cope with a changing climate include the following concepts: Room for the River, Building with Nature, Climate Buffers, Eco-engineering, Eco-Dynamic Design, and Nature-Driven Design. These concepts can all be considered natural coastal and river management approaches, in which water quality, water availability or safety against flooding in coasts and rivers are arranged in a way that they can be managed by nature with minimal human involvement. In these approaches, managers can restrict themselves only to maintaining this natural system. This way, the natural system plays a central role itself in adapting to a changing climate.

Room for the River ([11])
'Room for the River' is a concept that was initiated by the Dutch government and is now fully implemented in Dutch policy programmes. In the national Room for the River Programme, rivers are given more room to overflow at a total of 39 locations (Figure 2.2). This room is created in a number of ways, such as lowering of floodplains, relocation of dykes, de-poldering (allowing artificially reclaimed land to be submerged in water once more), or deepening the river bed. These measures all contribute to the restoration of parts of the historical appearance of the river system (meanders, wetlands). In addition to safety, the Room for the River Programme is concurrently investing in environmental quality: the river area is made more healthy and attractive, offering more room for nature and recreation.

Building with Nature programme ([12])
The 'Building with Nature' (BwN) innovation programme, coordinated by Project Bureau Ecoshape, has developed a variety of promising green adaptation approaches. An important innovation of the 'Building with Nature' programme has been the development of a design approach: Ecodynamic Development and Design (EDD). EDD aims to use the forces of nature to produce coastal defence infrastructure and create new opportunities for nature at the same time. As the dynamics of nature are better understood,

Figure 2.2 Illustration of Room for the River: a widened riverbed increases river discharge capacity

Source: © https://beeldbank.rws.nl, Rijkswaterstaat, the Netherlands.

([11]) More information: www.ruimtevoorderivier.nl.
([12]) More information: www.eco-shape.nl.

Figure 2.3 The Sand Motor on the Dutch coast near Ter Heijde

Source: © https://beeldbank.rws.nl, Rijkswaterstaat, the Netherlands.

the potential for further integrating nature in the development and design process is expanded. With new insights and knowledge, nature itself can become the driving force behind the sustainable development of coastal defence infrastructure. Building with Nature is also noteworthy for the close cooperation it creates between policymakers, designers, commercial companies, and project managers. Collaboration of this sort is a critical component of successful green adaptation approaches.

The 'sand motor' is one of the projects to emerge from the Building with Nature programme (more information: www.zandmotor.nl). In order to strengthen weak spots along the Dutch coast, annual sand nourishment activities need to be conducted along the coastline to prevent erosion (Figure 2.3). The Sand Motor is a large-scale nourishment programme, whereby 20 million m^3 of sand has been deposited in front of the Dutch Delfland coast. Unlike traditional sand nourishment, which places sand in its intended final location, the Sand Motor relies on wind, waves and sea currents to naturally disperse the sand further down the coast. By making use of natural coastal processes, nourishments should be needed only once every five or ten years, potentially reducing significantly maintenance costs compared to traditional coastal defence. The Sand Motor will contribute to coastal safety in the long term and also create areas for nature and recreation. The first pilot began in 2010–2011 and focuses on knowledge development in the fields of coastal morphology, hydrodynamics, and ecology. Preliminary results indicate that sand is indeed being transported along the Dutch coast, and at an even faster rate than expected.

Coastal protection through 'Building with Nature' is a step away from defensive design methods (aimed at minimising negative effects) towards design methods aimed at maximizing the potential of the natural system.

Climate Buffers ([13])
Climate Buffers was established as an NGO. Natural Climate Buffers is a concept within which

([13]) More information: http://www.klimaatbuffers.nl/english-homepage-2.

wetlands are maintained, restored, artificially created or enhanced (Figure 2.4). Wetlands include mudflats, swamps, reed fields in the Netherlands, marshes, mangroves and coral reefs. Besides being attractive areas where people like to live or recreate in, these areas can serve as water storage for cities, farms or industry. Subsidence of the soil is prevented in these areas through the root systems of wetland plants, helping to preserve or even restore biodiversity. The restoration of wetlands typically assists sedimentation — the process whereby rivers or the sea deposit solid organic matter in the wetland. This maintains the level of soil in the wetland, preventing subsidence and thus strengthening the coastal area, greatly increasing safety levels in the surrounding areas.

Administrative interactions
Building with Nature is administered by EcoShape, a consortium established by Dutch legislation. The EcoShape consortium consists of private parties such as dredging contractors, equipment suppliers, and engineering consultants. It also includes public parties such as government agencies and municipalities, applied research institutes, universities, and academic research institutes. The EcoShape consortium partners co-fund the Building with Nature programme, which also receives subsidies from the Ministry of Infrastructure and the Environment, the European Fund for Regional Development and the Municipality of Dordrecht.

Room for the River is lead partner for two EU projects, FloodResilientCity (FRC), and Adaptive Land Use for Flood Allevation (ALFA), subsidised in the INTERREG IVB North-West Europe (NWE) programme.

Results/lessons learned
The broad range of 'green' water management activities has provided many lessons.

Floods in the Netherlands would cause excessive damage, estimated in the range of more than EUR 100 bn. In creating 'Room for the River', the country has adopted a water management approach of prevention rather than evacuation and reconstruction. This new approach to flood protection — and the practical experience gained — is creating interest abroad. Countries around the world, including China and the USA, are keen to learn more about Room for the River and the technical and administration innovations to which it has given rise. And by participating in FloodResilientCity (FRC), and Adaptive Land Use for Flood Allevation (ALFA), the Room for the River staff learn from the experience and knowledge of European partners with similar problems, while allowing them to explain the situation in the Netherlands.

The Building with Nature programme takes a learning-by-doing approach by joining or initiating (pilot) projects in different environments (e.g. sandy shores, estuaries, shallow shelf seas and delta lakes). After implementation, the partners participate in the monitoring process and in the analysis and interpretation of the data gathered. In parallel, relevant knowledge gaps are being addressed by research projects, each of which is coupled with at least one on-going pilot project in order to link their work to real-world practice. As a final step, the partners are making a significant effort to ensure that the acquired knowledge contributes to practice via the Building with Nature Design Guidelines.

Figure 2.4 Illustration of climate buffers (left: a tidal marsh in the Eastern Scheldt estuary; right: reed swamp)

Source: © https://beeldbank.rws.nl, Rijkswaterstaat, the Netherlands.

It is critical to ensure that water does not pose a threat in the form of flooding, and that the water in our environment is clean. The knowledge gained from the Climate Buffers programme helps achieve this by finding the right balance between natural processes and hydraulic engineering.

The experience gained by the Netherlands can become an increasingly important export product, comprising not just civil engineering skills, but also architectural skills and landscape management.

Sources
http://www.ruimtevoorderivier.nl; http://www.ecoshape.nl; http://www.klimaatbuffers.nl/english-homepage-2; Hulsman and Maarse, 2010; Hulsman et al., 2011.

2.3.3 New varieties and production systems in the wine sector (Spain)

Adaptation goals
(i) Adapt the wine sector to new, long-term climate variability, climate change, and market constraints; (ii) Use grape varieties and production systems adapted to climate conditions.

Adaptation context
The growing scientific evidence for significant climate change in the coming decades means that adaptation will be of critical importance to the multi-billion euro global wine industry in general, and to quality wine producers in particular (Metzger and Rounsevell, 2011).

The diversity of wine production depends on subtle differences in microclimate and is therefore especially sensitive to climate change. A warmer climate will impact directly on wine-grapes through over-ripening, drying out, rising acidity levels, and greater vulnerability to pests and disease. This can result in changes to wine quality or potentially to the style of wine that can be produced (Metzger and Rounsevell, 2011).

The gradual temperature rise in the last 100 years (0.7 °C globally) has been accommodated successfully by gradual changes in wine management, technological measures, production control, and marketing (Metzger and Rounsevell, 2011). However, there is concern given that global warming could accelerate in an unprecedented manner.

However, changes in the wine sector will not be the result of physical changes in the climate alone. Changes in consumer preferences and the geography of global wine demand will also have a strong effect on which types of wine are produced and where. Moreover, changing grape varieties as an adaptation response to climate change has potential pitfalls, since consumers associate wine produced in a region with certain grape varieties.

Adaptation actions
In general, despite its success in adapting to the gradual temperature increases of recent decades, the wine industry is surprisingly conservative when it comes to considering longer-term planned adaptation for substantial climate change impacts. For instance, the wine industry adapts to climate change more by focusing on previously observed impacts and sustainable production (mitigation), rather than on forward-looking adaptation to cope with projected change in the future. Nevertheless, a few producers are expanding to new locations at higher altitudes or cooler climates. For example, the Torres brand is developing new vineyards high in the Pyrenees, and Mouton Rothschild is setting up new vineyards in Argentina and Chile. Signs of adaptation are even visible in the labelling system: the legal and cultural restrictions of Appellation d'Origine Contrôlée (AOC) systems are also being discussed (Metzger and Rounsevell, 2011).

The DEMETER project in Spain is another adaptation project focused on the wine sector. The DEMETER consortium is led by Demeter CENIT Bodegas Miguel Torres and composed of 25 Spanish companies linked to the wine sector, of which 67 % are wineries and the remaining 33 % are auxiliary industry companies in the wine sector. The consortium also includes 31 research groups.The project aims to provide technological responses to climate variation and climate change, based on field studies in Spanish vineyards. The first component of applied research led by the project aims to assess changes in gene expression of the grapes during the ripening process in the conditions of climate change (when grapevines face increased temperature and reduced water availability). It is hoped that this research will lead to the identification of biomarkers of maturity and ultimately to new adapted varieties of wine grape. The second axis of applied research is investigating changes in the production system so Spanish vineyards can adapt to climate change. The research will look at disease control and the development of precision viticulture, while also testing improved production systems (http://www.cenitdemeter.es).

The main actions to cope with impacts from temperature increase (e.g. + 3 °C) and rain

decrease (e.g. > 50 %) should be a combination of new genetic resources (new grape varieties) and improved management techniques (e.g. more water efficient irrigation, precision agriculture). This twin response is already being planned. For instance, at field level, the development of new genetic varieties or the use of existing adapted grape varieties is one of the key actions for adapting to new climate conditions. It will lead to new grape varieties that are best adapted to limited summer humidity and hot summers. Regarding production and management options, changes in agricultural practices could have significant short term environmental impacts and productive effects. For instance, the mere use of cover crops between vine rows to protect the soil and increase the number of species could significantly increase organic matter content, and thus improve moisture retention, and reduce soil erosion. Cover crops could also help reduce the use of fertilisers (given the increase in organic matter available), pesticides (given the increase of ecotones and niches for biological control) and herbicides (given that vegetation will be preserved). Overall, the field test shows that new management techniques, including precision agriculture and biological pest control, allow for the adaptation of the wine production system to new climate and market conditions.

Financing
In the case of DEMETER project, the total budget is around EUR 27 m for a four-year research project, financed 45 % by public funds and 55 % by the private sector.

Results/lessons learned
These adaptation experiments in the Spanish wine industry show that concern for climate change is already leading to a change in the investment plans of major wineries. The possibility that traditional patterns of viniculture may change dramatically must be taken seriously. Adjustments to AOC systems, and new marketing strategies are likely to remain high on the agenda of the European wine industry.

Sources
Metzger and Rounsevell, 2011; http://www.climatechangeandwine.com; http://www.cenitdemeter.es.

2.3.4 Restoration of peatlands (Ireland)

Adaptation goals
(i) Address potential peatland biodiversity loss as a consequence of energy exploitation and climate change; (ii) Exploit synergies between adaptation/mitigation on the one hand, and the restoration of ecosystem goods and services on the other hand.

Adaptation context
In their natural state, peatlands constitute an important reservoir of natural diversity, act as a sink for atmospheric carbon dioxide (CO_2), and are an important long-term carbon store in the terrestrial biosphere (Feehan et al., 2008).

Since the mid-1950s, large-scale mechanical exploitation of the larger raised bogs in Ireland has resulted in a decline of these important functions. In particular, so-called industrial cutaway peatlands release significant quantities of carbon dioxide to the atmosphere annually (Wilson et al., 2012). Climate change has added to the uncertainty of preserving peat ecosystems, some of which are already degraded and thus less resilient to change after peat harvesting. Jones et al. (2006) expect that, if the climate in Ireland changes as predicted, about 40 % of Irish peatlands could disappear by 2075, with a subsequent diminution of the biodiversity and carbon pool functions they provide, along with the loss of cultural and landscape-related services (e.g. recreation).

Adaptation actions
Active restoration of industrial cutaway peatlands has proven a successful response to their degradation as a result of energy exploitation. The original policy of Bord na Móna, the Irish Peat Board, was to plant harvested peatland with grassland or trees (coniferous and hardwood forestry). However, it quickly realised that a more integrated land use plan was needed, given the variable nature of the soil structure and drainage characteristics of these degraded peatlands. Thus, cutaway bogs were reshaped into a mixture of grassland, woodland, wetlands, natural peatland regeneration sites, lakes, and public amenity areas. The Lough Boora Parklands in County Offaly initially had over 2 000 hectares of cutaway, of which about one quarter were not suitable for commercial use (agriculture and forestry), and is a showcase example of this sort of mixed redevelopment (Egan, 1998; 1999).

Removal of the peat drastically alters the hydrology of a peatland. Thus, only limited areas in the cutaway peatlands have suitable hydrological and substrate conditions to allow for natural regeneration of the peat ecosystem (Feehan and Kaye, 1998). Turraun, the oldest area of cutaway at Boora, is one of those areas with such 'recolonisation' potential (covering ca 120 ha by

1990). Restoration of Turraun required closing off the drainage system and installing an embankment along the lower end of the area, leading to natural flooding (with internal spring systems and rainfall as water sources).

Results/lessons learned
The natural recolonisation of the Turraun wetlands at Lough Boora with new growth of peat has resulted in a mosaic of ecosystems that have spontaneously evolved in directions for which their natural character was best suited: birch and willow woodlands; open purple moorgrass grasslands; large areas of reedbeds; heather and moss areas; and intermediate wetlands with bulrush, bog cotton and sedges. Along with the wetlands, large areas of forestry and grassland were also developed. Following its rehabilitation, the habitat value of the Boora cutaway boglands has grown, and much more wildlife and plantlife has been recorded (including 110 bird species and 265 vascular plant species by 1999), some of which are the only remaining wild populations in Ireland (e.g. Grey Partridge).

A similar peatland restoration project was set up at an industrial cutaway peatland at Bellacorick, County Mayo. The site was restored in 2003, and this has resulted in a persistently high water table level throughout the study site, and the extensive recolonisation of the former bare peat substrate by a range of typical peatland species (e.g. vascular plant and bryophyte moss vegetation) (Wilson et al., 2012).

A persistently high water table is also necessary for maintaining or restoring the carbon pool function. Consequently, rehabilitation of degraded peatlands offers the potential to re-establish the carbon sink function characteristic of natural peatlands, and to reduce CO_2 emissions (Wilson et al., 2012).

With an estimated 90 000 ha of industrial cutaway peatlands left to be managed in Ireland, practical rehabilitation measures are invaluable options for the restoration of such lands against the background of climate mitigation and adaptation. Active restoration measures to facilitate natural ecological regeneration commonly include 'rewetting' of areas through blockage of previously-installed drainage systems. It may also involve the removal of recent tree growth (implying increased evapotranspiration and thus water abstraction) to prevent subsequent drying out of the peatland. In the case of the Boora Parklands, involvement of the local community has helped to produce an array of educational, amenity and tourism possibilities. Thus, such projects have addressed not only commercial interests, but equally environmental and socio-economic — in particular local community and economic development — concerns.

Sources
Bord na Móna. Lough Boora Parklands: http://www.loughbooraparklands.com; Egan, 1998; Egan, 1999. Feehan and Kaye, 1998; Feehan et al., 2008; Irish Peatland Conservation Council (IPCC): http://www.ipcc.ie/advice/peatland-management-diy-tool-kit/restoration-of-industrial-cutaway-peatlands; Irish Peatland Conservation Council (IPCC): http://www.ipcc.ie/peatland-action-plan/climate-change-and-irishpeatlands; Jones et al.,2006; Joosten et al., 2012. Paludikultur für Biodiversität und Klima: http://www.paludikultur.de; Wilson et al.,2012.

2.3.5 Sustainable forest management (Pan-European)

Adaptation goals
Increase the resilience and capacity of forests to adapt to impacts of climate change while continuing to provide goods and services.

Adaptation context
The development of adaptation measures for forests is an urgent task, as forests will grow under future climatic conditions that are significantly different to the current ones. Forests, when managed in a sustainable way, can play a central role in climate change mitigation and adaptation. The current definition of sustainable forest management is *the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, health and vitality, and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems* (Forest Europe, UNECE and FAO, 2011). It implies various degrees of deliberate human intervention, ranging from actions aimed at safeguarding and maintaining the forest ecosystem and its functions, to favouring specific socially or economically valuable species or groups of species for the improved production of goods and services.

Forests in Europe are very diverse. They are subject to different management practices depending on growing conditions and types of forest ownership. The impact of climate change in Europe is projected to vary across regions. Climate change is expected to increase forest productivity in northern Europe and in higher mountain altitudes — at least in the short-to-

medium-term. The impacts are likely to be negative in other regions of Europe due to increased average temperatures, and greater frequency of droughts, floods, heat waves, and fire and storm damages (Lindner et al., 2010). This could potentially result in severe reductions in the economic value of forest land (Hanewinkel et al., 2012). Public forests dominate in the central, east, and south-eastern part of Europe (where they make up more than 80 % of the forested area), whereas the average percentage of publicly-owned forests in western Europe is around 30 % (Forest Europe, UNECE and FAO, 2011). Several studies indicate that private forests provide more market-based goods such as timber, while public land produces relatively more energy wood, as well as multiple-use goods and services such as recreation, and provision of drinking water (Siry et al., 2009). This diversity of ownership and uses means it is important to pursue regional approaches to adaptation in forestry (e.g. within the Alpine Convention Protocol on Mountain Forests).

Adaptation actions

Despite uncertainty about the impact of climate change impacts on forests, there is a broad range of forestry activities that can already be implemented to adapt forest management plans. At national level, public forests can implement adaptation measures including: knowledge transfer and training; mapping of the vulnerability of forest species to a changing climate; and protecting forests against fires (EUSTAFOR, 2010). Governments can help forest owners ensure that forest adaptation practices are fully in line with management plans and practices that protect and maintain the multiple functions of forests and hence forest goods and services. However, a major barrier to the implementation of emergency responses and adaptation measures may be a lack of trained personnel in rural areas.

Forest stakeholder groups can be involved in the process of climate change adaptation by developing silvicultural and forest restoration techniques. This can establish a robust forest adaptation process, and create a sense of 'ownership' of the adaptation process among forest users. More attention needs to be directed towards the choice of tree species (taking account of the origin of the species and its genetic properties), as well as to choices of future silvicultural systems (taking into account for example rotation length, density of stems, and thinning practices). These issues can be targeted through establishment of local experiments and observation plots and used as a platform for manager/researcher cooperation and training.

An overarching management goal should be ecological diversity, with a variety of species, age classes and densities of trees across the landscape. Diversity enhances forest resilience to future challenges and increases the options available to forest managers to learn from climate change and respond accordingly. To minimise the impacts of climate change on forest ecosystems and forest-dependent people, flexible decision-making is required at regional, national and local levels to allow for adaptive forest management practices.

At regional level, forests can be managed in a sustainable way according to common guidelines to provide maximum benefits in terms of climate change mitigation and adaptation. At national and local levels, afforestation and forest regeneration are important ways of establishing suitable species and subspecies that can adapt in a sustainable way to new growing conditions. Risks related to natural disturbances, such as storms, insect infestation, drought, fire, and forest dieback can be reduced by choosing suitable tree species, thinning regimes, designation of fire breaks, and controlling soil humidity. These measures help ensure that forests remain healthy, reducing the risk of forest degradation and increasing resilience to climate change.

Depending on the main forest management objective, the focus of adaptation strategies may be on timber production, other ecosystem services (e.g. recreation), or reducing the risk of disturbance such as from extreme events (Figures 2.5 and 2.6) . Forest ecosystems have a natural ability to adapt to changing environmental conditions, but these spontaneous adaptation processes are not fast enough to cope on their own with rapid changes in climate. Therefore forest management needs

Figure 2.5 Post-fire landscape, Corsica

Source: © Annemarie Bastrup-Birk

to support a higher diversity of species either by natural processes or by planned adaptation measures. Many adaptation options can be combined, while others are mutually exclusive at the 'stand' (a group of trees) level. For example, improved forest regeneration can include adaptation measures that combine optimal choice of tree species, changing the spacing of trees, and even shifting planting season to enhance drought resistance. At the stand level, individual response strategies can be mutually exclusive. For example, preferring natural regeneration in mixed forests with long rotation cycles is incompatible with planting productive genotypes managed in short rotation cycles (Kolström et al., 2011).

Better resilience against heavy storm events — Germany

In the Black Forest area in Germany, forest management strategies have been developed to increase the capacity of the forests to tackle on-going climate change and improve resilience to heavy storm events. Local stakeholders of the forest are concerned about the changing climate, as a changing climate will directly influence reproduction, mortality and growth of the forests, with different impacts on different tree species. In 1999, the 'Lothar' storm destroyed large productive forest areas. Afterwards, parts of the forest were replanted according to traditional silvicultural practices, whereas other areas were left with spontaneously growing vegetation. It is unclear for many forest managers how to manage the forests under the assumption that storms are expected to occur with higher frequencies. Remaining old spruce stands are highly threatened by storms of this nature due to their age and height as well as stand structure, which is not adapted to current and future growing conditions.

The project MOTIVE (MOdels for AdapTIVE Forest Management under Climate Change) aims at simulating flexible forest management strategies under different climate scenarios. The simulation tool is currently extensively used to examine the effects of storms and climate change for several scenarios. The simulation tool is also used to evaluate management strategies that were developed in close collaboration with local stakeholders.

The Bavarian government's Climate Change Programme 2020 includes a module on mountain forest protection. The programme aims at stabilising mountain forests' vital protective functions through intensive care and redevelopment. It places special emphasis on effective regulation of hoofed game to minimise the damage caused to standing trees caused by browsing and bark stripping game such as deer. A state-wide information system will facilitate targeted responses in regional risk areas. The Bavarian Climate Change Programme 2020 encompasses several ecosystem-based initiatives. Along with reducing greenhouse gas emissions, the programme aims to enable areas that are particularly sensitive to the effects of climate change to best adapt to these impacts by 2020. To implement the adaptation component of the Bavarian Programme, EUR 84.7 m was made available from German national funds for the period from 2008 to 2011, of which EUR 7.5 m is reserved for mountain forest protection and EUR 15 m for the forest redevelopment programme. An additional EUR 350 m has been provided for the next four years to specifically address the conditions in Bavaria with tailored measures that address the fields of, for example, water, forests and forestry, agriculture, and health.

Administrative interactions

MOTIVE is supported by the European Commission under the Environment (including climate change) Theme (Project MOTIVE, ENV-CT-2009-226544) of the 7th Framework Programme for Research and Technological Development.

Sources

European Commission FP7 MOTIVE project: http://motive-project.net; Bavarian State Ministry of the Environment and Public Health, 2009.

Conversion of tree composition at local level — Poland

More resilient forest stands can be established by increasing the share of deciduous species, and ensuring the trees in a stand are of different heights, thus supporting greater biodiversity. These changes in silvicultural activities lead to increased forest stand resilience, carbon storage and forest sustainability. Ultimately, they contribute to a strengthening of the social, ecological and economic values of forests. A local-level adaptation initiative implementing these changes has been conducted in Poland. The initiative includes conversion of the composition of the forest, by planting more broadleaved species in most of the 430 national forest districts, which have traditionally held a larger share of coniferous trees. This effort has been included in national forest legislation, policies and guidelines. Historically, broadleaves accounted for 13 % of Polish forests in 1945, and its share increased to 23 % in 2008. This adaptation initiative

has also been assisted by the re-introduction of past forest management practices, such as reviving and restructuring forest stands.

Sources
Country report database of the COST Action ECHOES: http://echoes.gip-ecofor.org.

Increasing drought resistance of species — Spain
A special Spanish programme at national level has been developed to promote the availability of genetic material, enhance resilience to climate change in general, and enhance resistance to drought in particular. Reforestation programmes must be conducted using a variety of tree species. This will ensure the overall resilience of the newly planted forest in the event of disease striking a single species. Forest services in the Valladolid Province (Castilla y León) have proposed to apply intense early thinning of pine stands to increase growth and reduce the episodes of tree decay that often happen in the summer (Gordo et al., 2009).

The increased risk of fire, predicted for most forest regions in the coming years, means that new adaptation actions will have to be built into any forest management plan. These actions include: adequate selection of tree species; ensuring the right level of tree density in the stand; regular forest management; and improvements in fire-fighting techniques. Clear guidelines should be given on what types of fire-defence initiatives are most appropriate in view of the increasing intensities of forest fires (Moreno Rodríguez et al., 2005) ([14]).

Sources
Country report database of the COST Action ECHOES: http://echoes.gip-ecofor.org.

New silvicultural practices — France
At regional level in Haute Normandie in France, a project has developed guidelines to define thinning regimes and new harvesting criteria in accordance with changes in forest productivity expected from climate change. These changes imply a reduced rotation time for beech (*Fagus sylvatica* L.) to 100 years (currently it is 120–140 years) and for oak (*Quercus petrae*) to less than 200 years. Regional forest management planning directives were prepared for state forests in Haute Normanie, and the managers of community-owned forests in the region agreed in 2006 to also implement the proposed guidelines. For the 60 980 ha of public forests in Haute Normandie, the recommendations to include consideration of the effects of climate change in forestry planning have resulted in a redefinition of harvest criteria and the application of a more dynamic thinning regime. At local level also in Haute Normandie, adaptive management schemes include specific recommendations for forests. One such recommendation for the 'Bord Louviers' forest (Moreno Rodríguez et al., 2005) is to increase the percentage of oak in the forest from 21 % to 35 %. This recommendation was made because populations of beech (currently the most prevalent and economically important species in this forest) will come under threat from climate change: beech is projected to face severe problems with increasing temperatures, and could be replaced by oak due to its lower sensitivity to water stress.

Sources
Country report database of the COST Action ECHOES: http://echoes.gip-ecofor.org; ONF, 2011.

Strategies of forestry companies — Sweden
Several Swedish forestry companies have proposed adaptation measures, including: the use of new plant material to adapt to increased temperatures and changing hydrological regimes; adjusted silvicultural and management programmes with shorter rotation/harvesting cycle to take increased storm risk into account; improved forest roads to deal with warmer winters and limited access to winter roads; and development of forestry machines able to operate on non-frozen, waterlogged grounds. The companies only proposed a few measures to adjust to larger forest fire risk.

Many representatives also considered potential strategies for reducing the risk of disease. These included planting of mixed stands that replace spruce; more active forest management with increased thinning; using tree species with shorter rotation times, and increasing preparedness against insect attacks. Some of these measures might cause serious threats to biodiversity and other values. For example, planting exotic trees can result in invasive species flourishing and altering neighbouring ecosystems. Such potential impacts could be addressed through controlling invasive species and assisting the movement of vulnerable species to newly suitable habitats.

([14]) Several countries have conducted analyses of this topic, including France, which in its study on climate change and areas sensitive to forest fires proposes rules for preventive management in forestry (e.g. intensification of harvesting, choice of species; see Chatry et al., 2010).

Figure 2.6 Examples of forest management for adaptation to climate change

Forest regeneration with conversion to broadleaved species, Slovakia

Source: © Annemarie Bastrup-Birk

Mixed forests, regeneration with broadleaved trees, Slovakia

Source: © Annemarie Bastrup-Birk

Mediterranean forest with mixed domestic species, France

Source: © Annemarie Bastrup-Birk

Sources
Country report database of the COST Action ECHOES: http://echoes.gip-ecofor.org.

Adaptive silvicultural practices — Austria
The forest administration service of the province of Upper Austria has published guidelines to support forest managers in their choice of tree species. This was particularly motivated by a desire to adapt forests currently dominated by Norway spruce (*Picea abies*) to a changing climate. The booklet provides a simple site classification, and suggests suitable tree species including recommendations for spacing and mixture types. It focuses on promoting broadleaf trees for the production of valuable timber. In parallel, a network of demonstration plots in broadleaved stands has been established to provide practical training facilities, and to demonstrate the potential for production of valuable timber assortments. Within the ADAPT research project, adaptive silvicultural concepts for 160 000 ha of the Austrian Federal Forests (AFF) were designed and tested in a simulation-based scenario analysis (Lexer and Seidl, 2009; Seidl et al., 2010). Concrete recommendations were derived regarding choices of tree species and mixtures of tree species for different site conditions. The recommendations included shorter rotations and adapted thinning regimes to reduce the risk of storm and bark beetle damage.

Administrative interactions
The dissemination activities have been supported by the Austrian ADAPT project (Vulnerability of production forests of the Austrian Federal Forests Ltd under conditions of climate change and options for adaptation in silviculture).

Sources
Country report database of the COST Action ECHOES: http://echoes.gip-ecofor.org.

Results/lessons learned
The actions presented above demonstrate the importance of increasing the diversity of species in order to enhance the resilience of forests to future challenges. This will increase the opportunities available to forest managers to learn from climate change and respond accordingly. Furthermore, flexible decision-making at regional, national and local levels allow for adaptive forest management practices, which are necessary to minimise the impacts of climate change on forest ecosystems and forest-dependent people.

Forest stakeholders can decide how to react to climate change either by not intervening at all, by reacting, or by proactively planning the adaptation.

This section has presented some of the possible measures for the second and third options. A major part of the measures in the case studies involved the planting of new forest. As also mentioned by several adaptation specialists (Sedjo, 2010; Seppalä et al., 2009), this involves a series of decisions on where to locate the new forest, and which species to plant, in what quantity and of what quality. The consequences of these decisions on biodiversity, landscape, recreation and other services also have to be evaluated (Berry et al., 2009; MACIS, 2008).

Distinct effects of climate change were demonstrated on species composition, biomass production and biodiversity with clear trade-offs between the latter two. A mixed species approach appeared to be the best approach to deal with these trade-offs. Close collaboration between the local stakeholders and forest managers is extremely important to successfully run models and develop scenarios to redefine forest management practices and goals in view of climate change-related risks and uncertainties. Model developers have to learn from the local stakeholders, and have to build meaningful management scenarios based on this knowledge.

These examples of proactive adaptation include targeted regeneration and protection strategies to address long-term shifts in forest disturbance patterns. These actions are anticipatory and preventive in nature, and are more likely to avoid or reduce damage than reactive responses. Several studies highlighted the importance of the participation of forest stakeholders in adaptation actions. Their participation helps to: enhance the understanding of the impacts of climate change on forest resources; identify needs to assist decision-making; and support the dissemination of proposed adaptation actions.

2.3.6 Restoring the lower Danube wetlands to manage flood risks (Danube river basin)

Adaptation goals
Manage flood risks and related pollution issues.

Adaptation context
The Danube floodplains formerly covered an area of approximately 26 633 km², which is equal to about 3.3 % of the total Danube catchment area. The total size of the floodplain of the Danube tributaries (including the Drava, Sava and Tisza floodplain) was at one stage 79 406 km², equal to almost 10 % of the river-basin, or nearly the entire territorial surface of Austria. However, conversion of floodplains for farming and other development has dramatically reduced the size of the Danube system floodplains. The total floodplain area for the Danube was reduced by 68 % and the delta floodplain area was reduced by 35 %. The Danube's active floodplain is now 15 542 km². Dykes are responsible for most of this floodplain reduction. 95 % of the Upper Danube, 75 % of the Lower Danube, and 28 % of the delta's floodplains are cut off by dykes. This has increased the risk of floods and pollution in the region, threats that are expected to rise with climate change.

The assessment of ecosystem services and adaptation requirements in the Danube is informed by experience and earlier studies (e.g. existing governmental and non-governmental projects and proposals). Some options for restoration have been assessed.

Adaptation actions
In 2000, WWF secured agreement to restore 2 236 km² of floodplain to form a 9 000 km Lower Danube 'Green Corridor'. This corridor is intended to attenuate floods, restore biodiversity, improve water quality, and enhance local livelihoods. As of 2008, 469 km² of floodplain (14.4 % of the area pledged) has been or is undergoing restoration.

Some 8 % of the area of the Danube lay in 'near-natural' floodplains, including large project sites in the Danube Floodplain National Park in Austria, and Gemenc in Hungary, both of which are already partially restored. Compared to the overall loss of Danube floodplains at 68 %, it is estimated that about 24 % of the previously lost floodplain could be restored. The largest restoration potential is in Romania. The potential restoration sites vary in size, configuration and feasibility of implementation. Respecting the different purposes of floodplain restoration (such as flood protection, biodiversity, nutrient reduction, groundwater exchange, forestry, and recreation), the assessment initially focused on 'floodplain functioning'. Floodplain functioning is the preservation of the floodplain ecosystem so that it supports most of the ecosystem services listed above. Of the planned and proposed areas for the Danube, 33 (or 19 % of the total number of areas) receive a 'very high' restoration potential rating; 98 (56 % of the areas) receive a 'high' rating; and the remaining 45 (25 % of the areas) receive only a 'moderate' restoration potential rating. This first comparison of areas is based on commonly available parameters, and can be used to further discuss and develop restoration prioritisation. A short-term goal should be the definition and clear planning of one large-scale pilot floodplain restoration project per country in

the Danube basin by the next cycle of management planning in 2013.

Financing
Restoration of the pilot polders has seen a diversification in local employment to fishing, tourism, reed harvesting, and livestock grazing on seasonal pastures. These activities earn an average of EUR 40 per hectare per year. Restored floodplains provide ecosystem services for fisheries, forestry, animal feed, nutrient retention, and recreation that are estimated at EUR 500 per hectare per year, or around EUR 85.6 m per year for the restoration area. Following restoration, the number of resident breeding bird species increased from 34 to 72. As a result of its accession to the European Union, Romania has designated an additional 5 757 km^2 as 'Natura 2000' protected areas. Restoration of the 37 sites that make up the Lower Danube Green Corridor will cost an estimated EUR 183 m, but will likely generate additional ecosystem services worth EUR 85.6 m per year. Before the restoration, the 2005 flood cost EUR 396 m in damages.

Results/lessons learned
The protection and restoration of existing floodplains is vitally important and must take into account the highly dynamic characteristics of the river and wider ecosystem. Restoration of floodplains and other strategies for river development must therefore go hand in hand with the management of protected areas.

The availability of land is very important to ensure successful restoration. Ownership is often the most critical factor in ensuring the success of any restoration project. Favourable legal frameworks (clear protection of floodplain 'retention' areas upon which development is prohibited), strong spatial planning instruments, and administrative and political structures that allow for transparent public participation are therefore key requirements for successful restoration projects.

Comprehensive project impact assessments are necessary for successful restoration. These should cover local, regional and international levels and deal with issues such as flooding, ecology and other ecosystem services. At the outset of any project, managers must consider the requirements for local planning and approval by authorities (e.g. influence on localflood levels and water quality).

Sources
WWF, 2010; World Bank, 2010.

2.4 Soft adaptation actions

2.4.1 Regional early warning systems supporting people's health and safety (Italy)

Adaptation goals
(i) To maintain and enhance in Emilia-Romagna a health monitoring system that warns of emerging insect-borne diseases; (ii) To set up a warning and prevention system that monitors human health risks caused by heat waves in urban areas; (iii) To maintain a regional early warning system of meteorological and hydro-geological hazards in order to prevent and reduce risk to people and property.

Adaptation context
Climate change causes different impacts on people's daily lives, depending on the regions in which they live. Some of these impacts include: changes in the way insects spread diseases; new public health risks from bioclimatic discomfort (the negative effects on human health of climate change); the acceleration of the hydrologic cycle (the cycle that governs rainfall, and water evaporation); and the intensification of extreme water-related events.

The regional authorities of Emilia-Romagna have promoted the development of adaptation strategies to address the impact of these new threats.

In assessing the danger from insect-borne diseases, it is necessary to pay attention to the risk levels caused by new climatic scenarios, to identify the areas most vulnerable to insect-borne diseases, and to choose the best preventive measures. Asian tiger mosquito (*Aedes albopictus*) is one of the potential vectors of emerging tropical diseases, such as chikungunya, dengue and West Nile fevers. Insect-borne disease is growing in importance in Emilia-Romagna because the region had to manage the first two events of vector borne disease in Europe in the last five years: Chikungunya in the Romagna sub-region in 2007, and West Nile in wide areas of the Emilia plain in 2008–2009.

In the case of bioclimatic discomfort, the health effects related to high temperature and humidity levels are an important problem of public health. Extreme events, such as the heatwaves in the summer of 2003 in central and southern Europe, can place public health systems under extreme pressure. Moreover, climate change projections show that the intensity and frequency of heat-waves will be more important in the coming decades, increasing the problem of health effects caused by bioclimatic discomfort. People living in medium latitudes —

and especially in areas with a 'continental' climate — are more vulnerable. People living in urban areas are also subject to greater risk due to the urban 'heat island' effect.

Emilia-Romagna is also facing flood risk due to its location near the river Po. The Po is the longest river in Italy, and forms the northern boundary of the region. Due to climate change, the frequency of extreme meteorological events is expected to increase. Flash floods on tributaries and severe floodings on the Po itself have been become more frequent. The European Directive 2007/60/EC on the assessment and management of flood risks has to be integrated into the management of the Po river and its tributaries.

Adaptation actions

Monitoring of emerging insect vector borne diseases

A health monitoring system to prevent emerging insect-borne diseases has been implemented in Emilia-Romagna. The programme has three different elements:

a) monitoring is carried out by studies of the biology and movements of insect populations in selected sites (e.g. the port of Ravenna or in depots of used car-tyres, a favourite dwelling spot for insects). The monitoring also involves the capture of adult insects with traps, and the mapping and geo-referencing of selected sites;

b) pathogenic research by laboratory tests on groups of insects, using molecular biology and virological techniques;

c) increasing the awareness of insect-borne disease (e.g. lime, dengue and West Nile diseases) in the public health system and extension of disease monitoring to other new diseases. Communication with both specialists and the general public is an important part of the early warning system. The awareness campaign distributes information material and runs an advertising campaign. It also runs training courses on the symptoms and epidemiology of insect-borne diseases for family physicians, pediatricians, hematologists and neurologists.

The Regional Health Authorities make yearly contributions to municipalities for local prevention activities, such as monitoring of tiger mosquitoes, anti-larval treatments, door-to-door information campaigns and controls, and educational activities in schools. Regional laboratories continue to test sites around their area for insect-borne diseases. Information about the work of the Health Authorities, and the best way to avoid insect bites have been published on a web site (http://www.zanzaratigreonline.it).

Heatwave stress prevention plan

In Emilia-Romagna, a warning service to prevent and address the health effects of heat waves has been active since the summer of 2004.

The service began with heat forecasts for 23 sub-areas in Emilia-Romagna. Since 2006, specific forecasts for the region's main towns have been added to evaluate the urban heat island effect. Summer bioclimatic discomfort conditions are defined by the Thom index or Discomfort index (DI), which combines temperature and humidity values to produce a value for physiological discomfort.

Bioclimatic discomfort thresholds used in the forecasting system have been identified by mortality research carried out in the urban area of Bologna, the capital of Emilia-Romagna, in the period 1989–2003. The forecast is performed automatically and, if necessary, it is modified by an expert forecaster. Forecasts are produced from 15 May up to 15 September and quickly disseminated to regional public health institutions by e-mail.

Every day, the website of Arpa Emilia-Romagna (the regional environmental agency) publishes regional forecasts for the coming three days, as well as provincial bulletins with graphics and text (http://www.arpa.emr.it/disagio).

Early warning system for floods and landslides

The Emilia-Romagna regional authorities actively monitor precipitation, river flow, and landslides in the Apennines using a network of measurement stations and forecasting models. This monitoring supports the Regional Civil Protection Agency in preventing damage from floods and landslides. The body which carries out this work is the Centro Funzionale, an organisation that unites services from different technical agencies such as: the Hydro-meteorological-climatic Service of ARPA Emilia-Romagna, the Regional Civil Protection Agency, the Regional Geological and Earthquake Service, and the Regional River Catchment Service. Centro Funzionale can also call on a large network of volunteers in case of alert.

The real-time meteorological network of the Emilia-Romagna Region is made up of more than 300 rain-gauges and 250 hydrometers installed along the region's rivers, allowing the Centro Funzionale to monitor the whole territory of the region. These

tools can help better predict the probability of landslides or flooding.

The output of these monitoring tools is condensed into a daily hydrogeological bulletin, which contains an evaluation of the likelihood of flooding or landslides for different areas in Emilia-Romagna for the next day. The evaluation is ranked on a scale ranging from 'absent' to 'ordinary' to 'moderate' to 'elevated'. If one or more areas are rated as 'moderate' or 'elevated', an alert bulletin is issued by the Regional Civil Protection Agency. The monitoring activities of the weather forecasters and the hydrologists are carried out continuously (24 hours a day) in the Centro Funzionale when an alert bulletin is ongoing.

Financing
The whole monitoring system for emerging insect-borne diseases, including local campaigns for the specific control of the tiger mosquito, scientific research, and educational activities, is around EUR 9 m per year.

The yearly cost for the heat wave stress prevention plan is about EUR 5 m per year.

The specific cost of Centro Funzionale, including the monitoring activities performed by the technicians, is about EUR 6 m per year.

Results/lessons learned
The methods for operating and implementing early warning systems have to be agreed by all parties involved (e.g. government, the scientific community, and the wider society), and therefore an integrated and participatory approach is required.

Regional integrated adaptation strategies are an effective tool for addressing the impacts of climate change in various sectors.

Sources
http://www.arpa.emr.it/disagio; http://www.zanzaratigreonline.it; http://www.adbpo.it; http://www.arpa.emr.it/idrogeologico/index.asp.

2.4.2 *European early warning systems for forest fires, floods and droughts (Pan-European)*

Adaptation goals
Climate change, climate variability and socio-economic change all increase the likelihood of a number of problems, such as forest fires, floods and droughts. The projects listed below aim to increase the adaptive and coping capacity of people, regions, and economic sectors in the face of these challenges.

Adaptation context
Floods, forest fires and droughts don't stop at national borders, and it is expected that climate change will lead to an increase in the frequency and intensity of extreme weather events. To better protect citizens from floods, forest fires and droughts, the European Commission is sending alerts and constantly updated maps to national authorities so they can warn about upcoming threats and prepare their civil protection forces. Such early and reliable information helps to save lives, avoid property damage, and protect the environment. These European Commission actions on disaster risk reduction complement other Commission activities that are specifically targeted at adapting to climate change (see also Section 1.2). These early warning systems were developed by scientists at the European Commission's Joint Research Centre, in Ispra, Italy.

Adaptation actions
About 65 000 forest fires take place in the EU every year, burning approximately half a million hectares. Damage caused by wild fires in the EU is estimated at approximately EUR 2 bn per year. The European Forest Fire Information System (EFFIS) supports the services in charge of the protection of forests against fires in the EU and neighbouring countries. It provides the European Commission services and the European Parliament with updated and reliable information on wild fires in Europe. EFFIS is being further developed in close cooperation with the fire services in the 37 partner countries in Europe, North Africa and the Middle East.

EFFIS provides information on forest fire danger up to one week in advance, supporting the prevention and preparedness efforts of the partner countries. Additionally, the system monitors the evolution of active fires daily, using satellite imagery to provide up to two daily updates of active fires and the damage caused them. This information is essential in the case of critical fire events at country- and European level. It also supports the activities of the Monitoring and Information Centre of the EC Humanitarian Office (the Community Mechanism for Civil Protection), which coordinates international forest fire-fighting operations and can dispatch assistance. EFFIS also provides post-fire damage analysis, including the assessment and modelling of forest fire emissions and the estimation of post-fire erosion and soil losses. This information from EFFIS is the basis for policy discussions on forest fires at the European level.

Floods can have major impacts for society, the environment and the economy, making them amongst the costliest natural disasters in the EU. The European Flood Awareness System (EFAS) was developed at the Joint Research Centre in close collaboration with national flood forecasting centres in the Member States as well as several meteorological services with the aim of improving disaster risk management, in particular for a cross border event. Since January 2012, EFAS has been maintained and further developed as an operational component of the COPERNICUS Emergency Management System (under Regulation (EU) No 911/2010 on the European Earth monitoring programme (COPERNICUS) and its initial operations (2011 to 2013)) in support to the Monitoring and Information Centre (MIC) of the European Commission. Specifically, EFAS provides:

- flood warning information up to 10 days in advance. This information is designed to be complementary to national flood forecasting information and is distributed daily to the MIC and EFAS partner network;
- a European overview of ongoing and forecasted floods, providing the European Commission with useful information for the preparation and management of aid during flood crises;
- application of state-of-the-art weather forecasting and novel methods in probabilistic flood forecasting;
- research applied to on-the-ground operations.

EFAS now represents the first operational hydrological network on flooding. It comprises 33 partners from 22 countries. In addition to providing flooding information, continuous simulations within EFAS produce daily soil moisture maps of Europe. This information provides an instantaneous image of the current modelled situation of the water content across Europe. EFAS also provides different tools for displaying and analysing this information.

The European Drought Observatory (EDO) was developed at the Joint Research Centre in close collaboration with the Member States and regional and local authorities. At present, the EDO provides:

- European-wide data on drought-relevant indicators based on precipitation, soil moisture, and photosynthetic activity of the vegetation cover. Data are updated in daily, 10-daily and monthly time steps.
- National, regional and local drought indicators provided by the relevant competent authorities.
- Up to 7-day forecasts of soil moisture development.

The use of state-of-the-art weather forecasts and probabilistic ensemble forecasts for medium-to-long-range forecasting of drought probabilities are currently under development and testing.

In addition, the EDO provides background information, search tools, media information, factsheets, and tools for display and analysis of the information provided. Finally, the EDO occasionally publishes 'Drought News', providing in-depth analysis of the evolution of ongoing droughts.

Administrative interactions
The European Commission's Joint Research Centre financed EFFIS, EFAS, and EDO.

Results/lessons learned
EU-wide information and alert systems support national authorities to better protect citizens, and increase the adaptive and coping capacity of sectors and communities at risk. The benefits are a reduction in losses and damage (e.g. of lives, properties and the environment).

Sources
http://effis.jrc.ec.europa.eu; http://forest.jrc.ec.europa.eu/effis; http://efas-is.jrc.ec.europa.eu; http://floods.jrc.ec.europa.eu.

2.4.3 Insurance schemes against natural hazards (Switzerland).

Adaptation goals
Provide nationwide and comprehensive insurance coverage for all buildings against natural hazards.

Adaptation context
Switzerland has a long tradition of coping with natural disasters. Landslides and floods have shaped the landscape over thousands of years, and society has adapted to the risks posed by extreme events. But even the most modern infrastructure cannot provide complete protection from extreme events. Thus, the integrated risk management in Switzerland includes all levels of action: prevention, preparation, intervention, reconditioning and reconstruction. Insurance has played a critical role in overcoming the losses caused by extreme events in the past.

The damage caused by natural disasters has increased in Switzerland in recent decades. This development is mainly linked to socio-economic changes such as more assets in risk areas, and it is not clear to what extent climate change has contributed to it. So far, the insurance system has been able to cope with extreme events, and it will continue to play an important role in adapting to the expected increase in extreme events due to climate change.

Adaptation actions
In Switzerland, there are two insurance schemes that insure all buildings (i.e. private, commercial and public) and contents against natural disasters (storm, hail, flooding, snow-pressure, avalanche, landslide and falling rocks): the cantonal insurance monopolies (CIM) and private insurance.

Most CIMs were established in the beginning of the 19th century as providers of fire insurance. After a slew of severe avalanches in 1924 and other extreme events, insurance coverage was extended to damage from natural hazards. Today, the CIMs are present in 19 out of 26 cantons (which contain 80 % of all buildings in Switzerland), and are required by law to provide unlimited coverage (i.e. covering the entire cost for reconstruction/replacement) against fire and natural hazards. In the Waadt and Nidwalden cantons, the contents of the buildings are also insured by the CIMs. Since all buildings have to be insured, the system provides the largest possible spread of risks across the canton. However, since the CIMs only insure buildings in the specific canton, they lack the possibility of diversification across other markets (i.e. other insurance classes like liability insurance, health and life insurance) and geographies. Therefore, the CIMs buy additional coverage at the Intercantonal Reinsurance Association (IRV) for extraordinary events, and together they offer each other mutual protection against extreme events in the Intercantonal Risk Community.

In the remaining seven cantons (which contain 20 % of all buildings in Switzerland) where CIMs do not operate, natural disaster insurance is provided by private insurers according to the Insurance Supervision Act. Fire insurance is compulsory, and because natural disaster insurance is included in fire insurance contracts, natural disaster insurance is effectively mandatory. Building contents are also covered by private insurance, except in Waadt and Nidwalden. Since private insurance companies also insure other risks, and operate nationwide or even internationally, the natural hazards risks to buildings is well diversified. However, private insurers have also grouped themselves in a natural hazards pool in order to share the risk and pass it on to the international reinsurance market.

CIMs and private insurance companies do not restrict their activities to insurance, but also actively engage in the prevention of damage from natural disasters. In view of the expected increase in natural disasters due to climate change, both CIMs and private insurance companies will become even more important in promoting prevention measures to overcome rising costs due to these events.

Financing
Premiums for both CIMs and private insurance need to be approved by the Swiss state. Due to the large risk collective, premiums are below 0.05 % of the value of the insured property.

Results/lessons learned
The Swiss insurance system for buildings and contents has proven to be very efficient and successful in compensating for the damage caused by extreme events. For example, the flood of 2005 caused total financial losses of almost CHF 3 bn and was the single most expensive natural hazard that ever occurred in Switzerland, and the CIMs and private insurance companies were able to cope with the damage. Insured losses amounted to about CHF 2 bn (buildings: CHF 890 m; contents: CHF 800 m; business interruption: CHF 200 m).

Sources
OcCC, 2007; Pfister, 2002; Quinto, 2010; Swiss Confederation, 2008; von Ungern-Sternberg, 2004.

2.5 Combined adaptation actions

2.5.1 From restoring seaside towards integrated coastal adaptation (France)

Adaptation goals
(i) Prevent coastal erosion by restoring and rehabilitating beaches and dunes; (ii) Attenuate the effects of coastal swell; (iii) Improve the condition of coastal habitats, landscapes and species; (iv) Improve road traffic and transport along the coastal area.

Adaptation context
Coastal regions require an integrated management approach, which combines land use management, preservation of biodiversity and ecosystems, and local/regional development programmes. A range of adaptation options and responses are available

for integrated coastal management (see details in Section 2.2.1).

For centuries, salt marshes and wetlands in the Mediterranean littoral have been used and modified by humans, creating significant environmental impacts. In Languedoc-Roussillon, several initiatives have been put in place to restore and rehabilitate these modified wetlands, salt marshes, ponds and coasts. These disparate initiatives have now been united under an integrated coastal rehabilitation programme. For instance, in the case of the Thau watershed, a broad management programme has been led by the Thau Agglomeration since 2007. Its main goal is to prevent the erosion of the beach (e.g. Lido Sète) by using a sustainable development strategy that includes integrated water and waste water management, the restoration of degraded landscapes, the use of green infrastructure, and biodiversity conservation (e.g. extension of NATURA 2000 sites). The programme is conducted in partnership with all institutional stakeholders (European Union, the French government, the Regional Council, and local authorities). The French Conservatoire du Littoral (CDL), which is tasked with protecting and restoring natural areas of coastline, is also involved in the project.

Adaptation actions
The project was implemented at three different scales to restore natural cycles and implement integrated coastal management: local level, sub-regional level, and regional level.

At local level (see details in Section 2.2.1), 2012 saw the end of two main construction projects: the movement of the coastal road and the reconstruction of the dune. 2012 was also the year in which experiments began to maintain the width of the beach at 70 meters, by testing on the east side of Lido two innovative methods of protection against storms and probable sea-level rise: Ecoplage (launched in March 2012) and Geotube (from autumn 2012). These experiments will continue until 2014, and the best feature or combination of both processes will be deployed on the most fragile area of the Lido beach.

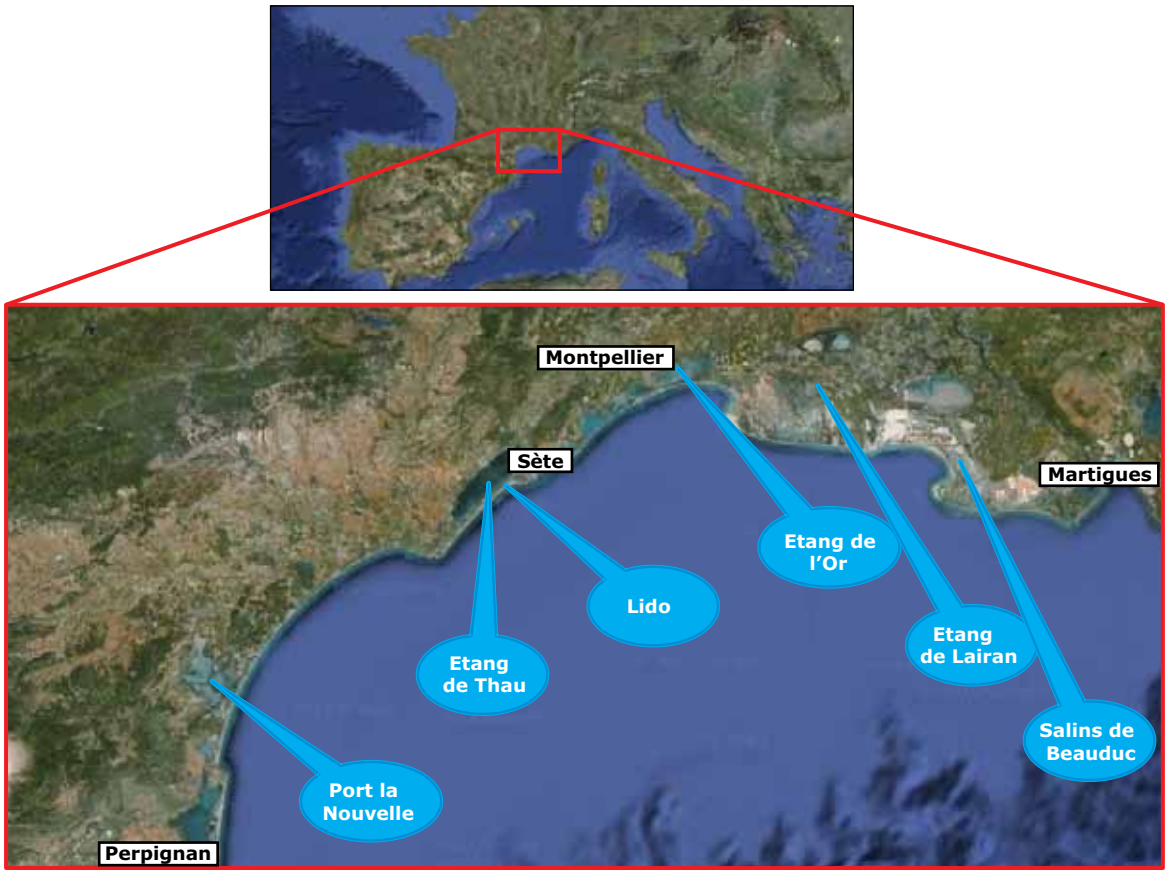
At sub-regional level, the increasing pressure from demographic growth, tourism, traffic, and disturbance to ecosystems has been affecting the Lido Sète 12-km stretch of sand, which separates the Étang de Thau (Thau lagoon) from the Mediterranean Sea. However, the Prefecture of the Languedoc-Roussillon Region, with ERDF (European Regional Development Fund) support, is managing a project to control damaging erosion processes by re-establishing sand dune ridges, re-orientating the road system, and developing pedestrian and cycle paths. Benefits for the local population and businesses will include positive and long-term impacts on tourism, better traffic flows, and protection of the dunes and lagoon areas.

At regional level, a series of actions took place near Sète city, around the southern side of the Étang de Thau, on a 140-hectare expanse of wetland that used to be the Villeroy salt marsh and now belongs to France's Conservatoire du Littoral (CDL). Four other sites are planned for restoration on the Étang de l'Or (near Montpellier), and on lagoons further along the coast near Port la Nouvelle, Aude (see Map 2.2). Since 2007, the Conservatoire du Littoral has also purchased a network of south coast salt marshes formerly owned by the salt company Compagnie des Salins du Midi (CSME). The salt marshes contain a unique ecosystem, and their acquisition by the CDL allows the restoration of these ecosystems to create a new 'green infrastructure' belt in this coastal and wetland landscape region. Further land acquisitions by the CDL are planned for areas around the Étang de Lairan, Gard and elsewhere. With each newly acquired site, the challenge is to find ways of turning former production facilities into world-class centres for nature conservation. These coastal sites are especially suited for conversion into favorable habitats for some bird species, which find expanses of open water in the summer that are isolated from terrestrial predators. For species such as pink flamingos in particular, the basins are a great source of food, and of opportunities for reproduction.

As part of this integrated conservation strategy, an EU-funded LIFE project, carried out by the Camargue National Park and the NGO Tour du Valat, helps to implement the new management objectives of the ancient Beauduc saline, which was also acquired by the CDL from the Saline de Giraud. There is currently a possibility of the shoreline retreating inland due to coastal erosion of the lagoon. The LIFE project seeks to better connect the management of water in the site with the central system of ponds in the Rhone delta. The project also seeks to protect nesting flamingos in what is their only breeding site in France (see Map 2.2).

Financing
In the case of the three-level Thau Agglomeration project, the European Union, via FEDER funds contributed 20 % of the cost. The French government, via FNADT and CDEP funds, contributed 30 % of the cost. The Languedoc-Roussillon region and Département de l'Hérault contributed 30 % of the cost and the Thau Agglomeration contributed the remaining 20 %. In the case of LIFE project, the

Map 2.2 Location of actions for integrated coastal adaptation



EU LIFE programme contributed 50 % of the total cost, and the French Ministry for the Environment, Conservatoire du littoral, Agence de l'eau (Plan Rhône) and PACA Region contributed the remaining 50 %.

Results/lessons learned

The key challenge in this adaptation programme was the integration of the different decision levels and resources to ensure appropriate responses. Unusual ecosystems such as salt marshes can be integrated into a green infrastructure network and rehabilitated to provide new ecosystem services. These adaptation measures reduce risks from storms, flooding and erosion. People are also able to use these recovered and restored landscapes given the newly adapted transport infrastructure and improved accessibility for recreation. Although these actions will make the coastal region more resilient to climate change, they will not make the area immune to its effects. A monitoring system should therefore be developed to keep a close eye on how these measures respond to the continuing evolution of climate variability (e.g. storms) and climate change (sea-level rise).

The adaptation measures also highlight the importance of involving all stakeholders and actors at the different levels of decision-making to ensure the best formulation and implementation of the management plans.

Adaptation actions are closely linked to other issues such as landscape management, tourism or road traffic, all of which also fall within the remit of integrated coastal management.

Sources

EEA, 2010b; Parc National de la Camargue: http://www.parc-camargue.fr; Thau agglomération: http://www.thau-agglo.fr/-Le-developpement-durable-.html; http://www.parc-camargue.fr/index.php?pagendx=1080#ref_1092.

2.5.2 *Flood risk management and the Thames Barrier (United Kingdom)*

Adaptation goals
To develop a long-term strategy for flood risk management for London and the Thames estuary that is risk-based, sustainable, and addresses the issues in the context of the climate and socio-economic scenarios over the next 100 years.

Adaptation context
Through its 'Thames Estuary 2100' (TE2100) project, the Environment Agency has developed a long-term strategy for flood risk management in the estuary ([15]). The overarching aim of the project was to develop a Flood Risk Management Plan for London and the Thames estuary that: is risk based, takes into account the existing and future assets, is sustainable, is inclusive of all the stakeholders, and addresses the issues in the context of the climate and socio-economic scenarios that could develop over the next 100 years (Jeuken and Reeder, 2011).

It took 30 years to plan and build the current system of defences following the 1953 flood. The Thames barrier was originally designed to protect London against a large storm surge (with a return period of one-thousand years up to the year 2030; Reeder and Ranger, 2011) and long-term changes in sea and land levels. However, given the long timescales needed for upgrading such infrastructure and the possibility that in less than 20 years the River Thames tidal defences might no longer be able to cope with rising sea levels, it was time to commence planning for the next generation of defences for London and the Thames estuary. The TE2100 Plan recommends that a major upgrade to the system will be needed by 2070 assuming 90 cm of sea-level rise.

Adaptation actions
What change can the Thames flood defence system handle before we run into trouble? For the TE2100 project this question focuses on two main elements: sea-level rise and increases in peak river discharge. Both of these elements can cause technical failure or overtopping of the flood defence system, including embankments, flood walls, and the Thames Barrier itself.

The TE2100 project gives a concrete example of flexible and robust decision-making in the light of deep uncertainty. This decision-making follows a so-called 'adaptation pathway' approach (Jeuken and Reeder, 2011).

Figure 2.7 shows the adaptation pathway map generated by TE2100 (for further information on adaptation tipping points and adaptation pathways see Section 4.3). It identified four different possible strategies or packages of measures (called 'High-Level Options': HLO1, 2, 3a, 3b, and 4) (Jeuken and Reeder, 2011). Together, these strategies were designed to span the estimated plausible range of increases in extreme water levels in the Thames by 2100 (i.e. up to 4.2 m). The decision maker can test the suitability of each strategy under a range of different climate change (primarily sea-level rise) and socio-economic scenarios to understand how appropriate and robust it is. For example, HLO1, which considers improvements to the current Thames Barrier, is appropriate for a sea-level rise of up to around 2.3 m. This option would be sufficient given current 'most probable' estimates of future sea-level rise in the Thames (90 cm). Each HLO consists of a pathway through the century that can be adapted to the rate of change that is experienced. Only HLO4 will cope beyond the revised worst case (2.7 metres) for the 21st century.

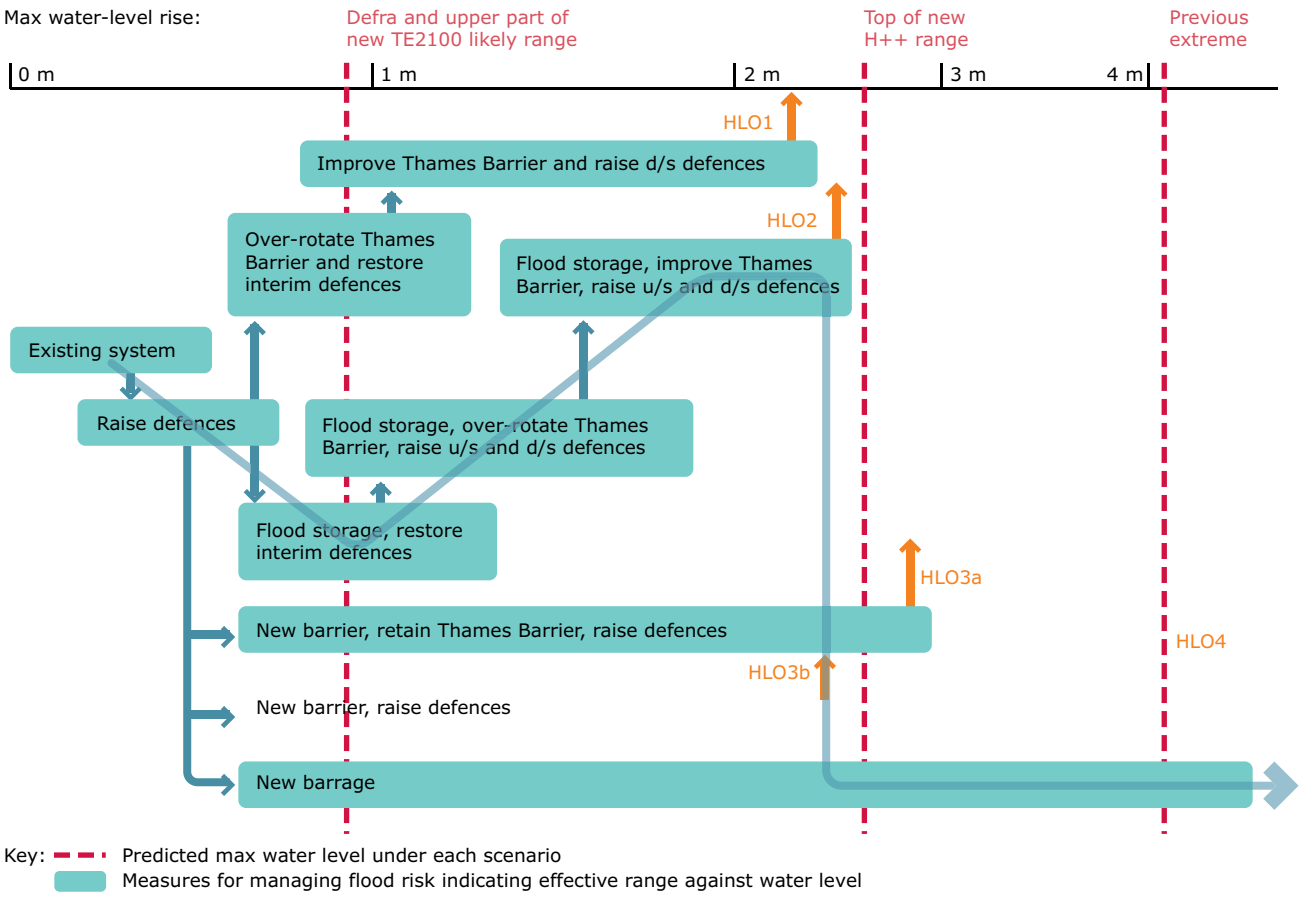
Not only are the High-Level Options themselves flexible (as they consist of several measures), but it is also possible to move from one adaptation option to another, depending on the actual rate of change that occurs in reality. If monitoring reveals that water levels (or another indicator, such as barrier closures) are increasing faster (or slower) than predicted under current projections, decisions may be brought forwards or postponed to ensure that they are made at the right time to allow an effective and cost-beneficial response. The investment plan for TE2100 contains detailed guidance on how its recommendations should be applied in the event of the more extreme change projections being realised, or in the event of a change in socio-economic development. It also shows how the time allotted for preparing major interventions needs to also take account of any such changes.

The effectiveness of the final plan will depend on a continuing process of regular review. The framework is designed to withstand uncertainty, but its successful implementation will require on-going monitoring and continuous review of decisions in light of updates to projections and new observations of sea levels.

Administrative interactions
The science research component to produce the revised projections of extreme water levels was

([15]) http://www.environment-agency.gov.uk/homeandleisure/floods/104695.aspx.

Figure 2.7 Adaptation Pathways map developed by TE2100 (on the y-axis) shown relative to threshold level increases in extreme water level (on the x-axis)



Note: The blue line illustrates a possible pathway or strategy where a decision-maker would initially follow HLO2 then switch to HLO4 if sea levels were found to increase faster than predicted.

Source: Reeder and Ranger, 2011.

led and financed by the UK Environment Agency, working with the Met Office in partnership with the National Oceanography Centre at the University of Liverpool and the Centre for Ecology and Hydrology (CEH).

Results/lessons learned

The implementation of the Thames infrastructure is subject to increasing information about the extent of sea-level rises, storms urges and coastal erosion. The adaptation pathways approach is particularly relevant when dealing with long-term problems of this nature, yet it is resource-intensive. These long-term problems are created by gradual changes, and by the fact that responses have long lead-times before they are fully implemented. For example, infrastructure for addressing coastal flooding requires considerable financial resources, and is very difficult to alter half-way through construction and operation.

Regular monitoring, evaluation and learning are critical to an adaptation pathways approach, so that alternative adaptation options and strategies can be called upon if and when relevant (for example, they can be brought forward in time or delayed). This flexibility supports adaptive and resilient management, cost effective practices, and helps avoid maladaptation — the selection of bad adaptation choices. However, the adaptation pathways approach also raises a difficulty in that trends in the occurrence of extreme events such as peak discharges from rivers are difficult to detect, because of high natural variability and the short time period of measurements (Diermanse et al. 2010).

Sources

Jeuken and Reeder, 2011; Reeder and Ranger, 2011 and Diermanse et al., 2010.

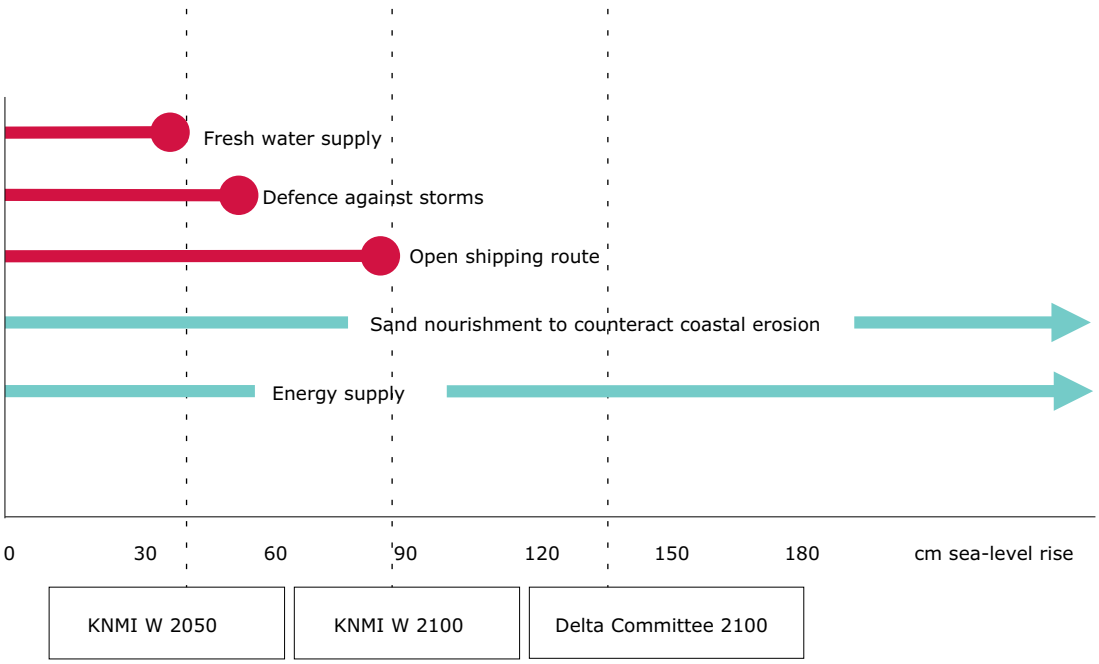
2.5.3 *Floods, freshwater and the Dutch Delta Programme (the Netherlands)*

Adaptation goals
To protect the Netherlands from flooding and to ensure adequate supplies of freshwater for generations ahead.

Adaptation context
In the Netherlands, the Delta Programme has been initiated *to protect the Netherlands from flooding and to ensure adequate supplies of freshwater for generations ahead* (Delta Programme, 2011). The chair of the Delta Programme summarised the main challenge of the programme as follows: *One of the biggest challenges is dealing with uncertainties in the future climate, but also in population, economy and society. This requires a new way of planning, which we call adaptive delta planning. It seeks to maximise flexibility, keeping options open and avoiding 'lock-in'* (Kuijken, 2010). This adaptive delta planning approach allows the Netherlands to combine flood safety and water security with other policy goals, such as economic growth, spatial planning and nature protection. The approach is flexible enough to allow changes to be made to the adaptation strategy to cope with changing knowledge on the impacts of climate change (Jeuken and Reeder, 2011; Delta Programme Commission, 2010). An example of this flexibility is sand nourishment along the coast. Sand is sprayed onto the coast based on the measured rise in sea level. If sea levels rise more quickly, more sand will be sprayed (Delta Programme Commission, 2010).

Adaptation actions
In the Netherlands, the adaptive delta planning approach focused on identifying the so-called Adaptation Tipping Points (ATP), where the objectives of water management policy (including coastal and river flood protection, and fresh water supply) are no longer met (Kwadijk et al., 2010; for further information on adaptation tipping points and adaptation pathways see Section 4.3). Figure 2.8 shows some results for the Rhine-Meuse estuary (Jeuken et al., 2010). It shows that the current strategy for fresh water supply fails in the event of a 35 cm sea-level rise, and that under a pessimistic scenario, this could occur before 2050 (KNMI W+). Under an optimistic scenario, the current water supply strategy could hold until the end of the century. The figure also shows that the strategy of coastal defence through sand nourishment will continue to be effective past the end of the century, even if the most pessimistic (and low probability) scenario of the Delta Committee is used (a 130 cm rise in sea levels by 2100).

Figure 2.8 Adaptation tipping points for the Rhine-Meuse estuary



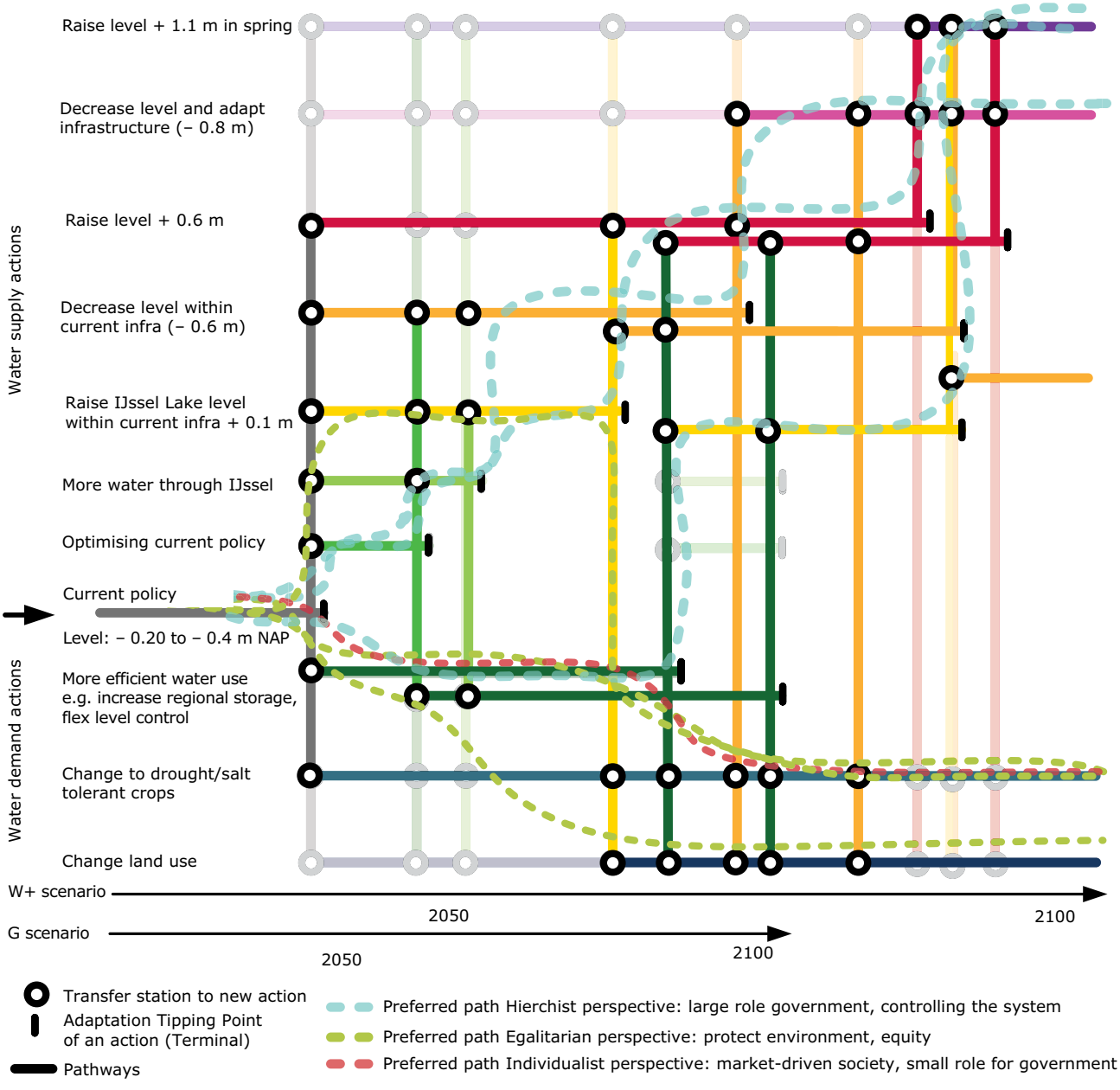
Note: Red bullets indicate endpoints of a strategy, blue arrows indicate the strategy can cope with higher sea levels. The climate scenarios used in the Netherlands are marked with dotted lines.

Source: Jeuken et al., 2010.

Adaptation pathways describe a strategy or sequence of policy actions (Haasnoot et al., 2011 and 2012a). Within the framework of the Delta Programme, different strategies and pathways are being elaborated to support decision-making on the so-called Delta decisions in 2014. These decisions are likely to have three elements (that are somehow similar to the Thames Barrier example, see Section 2.5.2): (1) What are the preferred pathways? (2) What are the points at which decisions have to be made?, and (3) what decision must be taken first in order to be prepared for the future?

Figure 2.9 shows an example of the adaptation pathways approach for the Rhine Delta-IJsselmeer area (Haasnoot et al., 2012b), which consists of the Markermeer and IJsselmeer lakes. The Afsluitdijk dam protects the adjacent areas from flooding, and captures fresh water supplied by the IJssel river. During dry periods, water from these lakes is used to supply large parts of the Netherlands. In the future, climate change and socio-economic developments may result in an increase in demand for water to flush fields due to more salt intrusion or because of changes in the agricultural sector. The

Figure 2.9 Illustration of adaptation pathways for the Rhine Delta-IJsselmeer case



Source: Haasnoot et al., 2012b.

future may also see reduced fresh water availability in the summer due to less rain and reduced river discharges; or because of salt intrusion in the rivers. Flood risk is also a concern for the future due the possibility of higher sea levels, greater river discharges in winter, and population and economic growth.

To construct the pathways, the policy actions were grouped into two groups: actions influencing water demand and actions influencing water availability. Some actions have a long 'sell-by date', meaning that they may be relvant over a long period of time (e.g. they could be implemented today based on a pessimistic scenario, or in ten years' time based on an optimistic scenario). Other actions have a short 'sell-by date' meaning that they are only relevant over a shorter period of time. Actions with a long 'sell-by date' are drawn on the top or bottom of the adaptation pathways map, while actions with a short sell-by date (those that will stop being useful earlier) are drawn close to the current policy, which occupies the middle part of the graph. Unnecessarily restricting options were eliminated (and illustrated with a 'shaded' background colour instead of bright colours for logical options). For example, implementing one of the largest actions first would be unnecessarily restricting, as this reduces the flexibility of the approach and locks in a particular pathway for a long period of time.

From the total set of pathways, 'preferred' perspectives were developed. These preferred perspectives were formulated to be hypothetical representations of the preferences of stakeholder groups according to their values and beliefs. These preferred perspectives do not follow a straight line, and can switch between different adaptation pathways options. The point at which a preferred perspective moves up or down to a new horizontal pathway line is a decision point. We can see two major decision points — after the 'current policy' pathway and the 'raise the IJsselmeer level within current infrastructure' reach their sell-by date.

Signposts and triggers can be used to implement contingency actions or call for a reassessment of the dynamic policy plan. Potential signposts are trends and events that can signal the need for a change in adaptation. Signposts can be trends in the natural environment (sea level, precipitation); human-driven impacts on the water system (autonomous adaptation of farmers); and societal perspectives. Triggers are often the events and phenomena that cause these signposts to develop. For example, the amount of land dedicated to agriculture used could be an appropriate trigger for changes in water demand.

The adaptation decisions taken will not only depend on the critical thresholds or adaptation tipping points, but also on the extent to which other measures for adaptation or other purposes were also implemented at the same time. Planned retrofitting projects in urban areas, for instance, may be combined with dyke reinforcements. This provides opportunities to implement combined measures and increase the efficiency and effectiveness of actions. However, they also raise major governance issues about who is to pay and who is to decide (Jeuken and Reeder, 2011).

Administrative interactions
The new Delta Plan is being implemented under the direction of the Delta Commissioner, a government appointee whose position is anchored in the Delta Act, an act of the Dutch parliament ([16]). The Delta Act has become effective on 1 January 2012.

Results/lessons learned
The UK Thames Barrier has pioneered the adaptation pathways approach, which is now being implemented across the Netherlands (Dutch Delta Programme).

Large-scale decisions often require long-term planning and considerable financial resources, and are typically subject to increasing flows of information over time and irreversibility once major construction work has begun. In spite of these constraints, they can be made more flexible in the face of deep uncertainty over future climate and socio-economic developments by using an adaptation pathways approach. This allows policymakers and planners to look at the durability, robustness and resilience of particular strategies across sectors and under different socio-economic, eco-systemic, climatic, and governance conditions.

The adaptation pathways approach is being increasingly used by other key stakeholders, including cities. Illustrative examples of how the approach works in practice can help improve attempts to integrate uncertainty and flexibility into decision-making. These examples also help show how to manage trade-offs between different investments that build resilience at different times.

([16]) http://www.deltacommissaris.nl/english/topics.

Sources
Delta Programme, 2011; Kuijken, 2010; Jeuken and Reeder, 2011; Delta Programme Commission, 2010; Kwadijk et al., 2010; Jeuken et al., 2010; Haasnoot et al., 2011, 2012a, 2012b and 2012c.

2.5.4 Portfolio of actions in urban areas (Pan-European)

Adaptation goals
Cities are home to the majority of the European population, and are the places where most of Europe's wealth is generated. It is therefore critically important to ensure that cities continue to function well, and provide a high quality of life for their residents, despite climate change resulting in higher temperatures and heat waves, more flooding or water scarcity.

Adaptation context
Climate change risks for cities are different than for rural or other areas. In addition to sharing many of the climate change problems as their surrounding regions, cities face specific impacts, caused by the way they are designed, and by the types of activities that are prevalent in urban areas. Below are some examples of recent climate-change impacts that are unique to cities:

- The majority of fatalities in the extreme 2003 heatwave and other heatwaves were found in cities. This is firstly due to the simple fact that cities are home to 75 % of the European population. However, it is also due to the fact that the way cities are designed and used: cites create an urban 'heat island' effect, caused by sealing of surfaces with concrete and asphalt, and heat sources such as traffic and industrial plants. Air conditioning is surprisingly also a heat source that contributes to the 'heat island' effect. Although they obviously create a cooling effect indoors, air conditioners also release a lot of heat into the atmosphere. Heat generated from all these sources is trapped by the high density of buildings, with very little in the way of green areas to disperse the heat or provide any relief for citizens. Many of the fatalities in the 2003 heatwave were children and the elderly.

- On 2 July 2011, Copenhagen, Denmark was hit by around 150 mm of rainfall within a few hours. It ran into the sewage system, which could not cope with this volume of water, placing most of the city under water. The typically high share of impermeable surfaces or soil sealing in urban areas prevents most water from draining into the ground, making cities particularly vulnerable to flooding.

- High population densities and economic activities lead to water consumption that makes cities dependent on the supply from a much wider region. Athens, Istanbul, Paris and others have developed extensive networks for transporting water, often more than 100–200 km to their city. Barcelona addressed its water scarcity and drought issues through 'demand management' measures such as (incentives to reduce the consumption of water) and supply-oriented technological solutions (see details in Section 2.2.3). A drier climate will put more stress on cities' water supply (EEA, 2010a).

- The high population density of contemporary cities makes them especially vulnerable, and as cities continue to grow in terms of population and built infrastructure, this vulnerability is likely to increase. The damage of the 2002 Elbe flood in Dresden, Germany was much higher than in comparable floods in the 19th century due to the much larger size of the city: although the flooded area was roughly the same size, the urban area had increased by four times since the earlier floods, leading to a significant increase in the number and value of the assets exposed (Schumacher, 2005).

Adaptation actions
There are many adaptation options available to cities (see Figures 2.10 and 2.11). Technical and green infrastructure can be used to protect cities against climate impacts. Soft measures like legislation, awareness-raising, knowledge and information sharing, and emergency plans can increase preparedness to cope with impacts. The following illustrative examples provide a glimpse of the possibilities.

Urban growth continues in the Netherlands, but there is very little space left for development that is not in danger of flooding. Amsterdam and Almere have thus created man-made islands with floating houses that can accommodate climate change instead of keeping water away.

Lodz in Poland has recently suffered from flash floods caused by heavy rainstorms. Over the last century, industrialisation and urbanisation had changed the surroundings of the city, and reduced the water absorption capacity of the land. To prevent further damage from these floods, Lodz has decided not to build traditional flood protection measures. Instead, the city is working with nature and acting

Figure 2.10 Examples of urban adaptation measures: sustainable urban drainage (left) and early warning systems (right)

Source: © Birgit Georgi

beyond the city borders — restoring river valleys to their natural state, and building reservoirs and storm water bio-infiltration systems (Loftus, 2011).

Water stress in Cypriot cities is a major environmental concern: the country has the highest water exploitation index in Europe. In 2008, Cyprus suffered a fourth consecutive year of low rainfall, and the drought situation reached a critical level that summer. As an emergency measure to ease the crisis, 30 water tankers sailed in from Greece, and households were supplied with water in twelve-hour periods only three times a week. This last-resort action falls under the category of emergency measures rather than adaptation measures and its financial and environmental costs and benefits should be further analysed. Among the measures now being implemented for solving the water problem are water efficiency measures (particularly in agriculture; EEA, 2012a), increasing water prices, increasing the number and capacity of desalination facilities, and transferring water from further away in rural areas to the cities. These approaches require integration with regional and national policies in order to exploit synergies, take advantage of the latest technology, and avoid maladaptation.

Zaragoza, Spain overcame its water scarcity problems by developing a water-saving culture using its local legislative powers and a broad participatory approach (EEA, 2012b; Shirley-Smith et al., 2008). Awareness-raising campaigns changed citizens' behaviour; while voluntary commitments, revised water tariffs and the introduction of water meters gave incentives to save water. Leakage control led to further reductions in water wastage. The government also drew up a municipal order to save water, to be incorporated in the Municipal Building Code. Overall, the city reduced water consumption by 30 % over the past 15 years in spite of a 12 % increase in its population (Philip, 2011).

A local non-governmental organisation, Ecodes (Foundation for the Environment and Development), was founded specifically to help reduce water usage in Zaragoza, and worked closely with the municipality to inspire and support water-saving initiatives. Water quality also improved during the process. Importantly, Ecodes enjoyed the full support of the municipality and managed to secure the engagement and support of the public through a clear and well-structured publicity campaign. The water-saving campaign became a matter of civic pride disassociated from party politics, and therefore survived several changes of government.

Reducing heat through city design is another adaptation measure that is being implemented. Heat is a problem for southern European cities, and traditional city design tried to deal with this by using thick walls, window blinds or the famous canopies over Seville's streets. Old Moorish parks in southern Spain also demonstrate the cooling effects of green infrastructure. In a modern update on these features, the 'Eco-Boulevard' of Madrid uses large cylindrical cooling towers made of a thin metal

structure with vegetation inside to provide a cool respite from the heat.

Milan, Italy has also to cope regularly with heat, and has developed the Piano Anticaldo — an action plan to prevent and limit the human health effects caused by heat waves. Throughout the summer, elderly and disabled people in need can use a toll-free number to request advice and services, such as meal delivery and home care. The plan is organised by the municipality, the local health authority and the hospitals.

Western and northern European cities could learn from the experiences of the south of Europe. While northern European cities have not traditionally suffered from heat problems, climate change means that more heat waves are expected there. As a first step, the municipality of Botkyrka, Sweden prepared for greater heat by mapping the places of residence of vulnerable people. This proved helpful in assisting them during the 2010 heat wave. After the 2003 heat wave, which also hit north-western Europe, several cities and countries established heat alert systems. France set up CHALEX, a monitoring system that checks on the health of vulnerable people (who have registered themselves as vulnerable by notifying CHALEX) during heatwaves. The 'Plan Canicule' in Paris and Geneva are also good examples of urban heat wave action plans. They involve heightened monitoring by public services of the health of elderly and vulnerable people during heatwaves. Budapest, Hungary has coupled its heat alert system with a smog and UV alert system, which proved helpful during the 2007 heat wave, when mortality rates fell compared to previous heatwaves of similar intensity.

Stuttgart, Germany has long dealt with heat island effects by using green infrastructure and maintaining natural ventilation channels. Starting in 1938, it developed a unique in-house knowledge base on the effects of the climate on the city. This repository of location-specific weather and climate information supported the development of a climate atlas (2008), which highlights those areas that are key to improving local climate. A substantial share of the city area is covered by parks (Kazmierczak and Carter, 2010).

Copenhagen formulated an urban flooding action plan after the 2011 floods. Quite soon, it became clear that taking measures to avoid all damages from such a rare event in the future would require massive investments. The analysis showed that the best trade-off between costs and protection

Figure 2.11 Examples of urban adaptation measures: green infrastructure (top), blue infrastructure (middle) and urban and building design (bottom)

Source: © Bogna Kazmierczak

Source: © sxc-Xpgomes

Source: © inhabitat.com

levels would be to implement measures targeted to cope with flood intensity that would occur once in 100 years. Implementing these measures would mean accepting that in the event of a once-in-100-year flood, there would still be up to 10 cm of flooding (COWI, 2012).

One obvious place to begin in the Copenhagen flood protection plan is upgrading the sewage system. Other adaptation options include water management at surface level, by means of adding more green areas to the city, such as by altering roads, and public squares. The cost-benefit analysis calculations for Copenhagen showed that water management at the surface alone would be more expensive and provide lower protection levels than a combined solution, which included some surface level measures as well as changes to some of the underground infrastructure like the sewage system and tunnels (COWI, 2012). Such a solution could avoid roughly two thirds of the damages, but it would still result in building and maintenance costs that were higher than the value of the damage avoided. A more cost efficient measure is the installation of 'return valves' (that drain out flood water) in all basements, which has a cost benefit ratio of 1:4. However, this measure on its own would only avoid around one third of the damages, and would require that all property owners install them. A combination of the measures mentioned above would bring down the damage cost, but still cost more money than it would save. But it was estimated that broadening the scope of adaptation measures beyond the administrative borders of the commune of Copenhagen to include the neighbouring commune of Frederiksberg would be cost effective. It is worth mentioning that the ancillary benefits of adaptation measures were not included in the cost-benefit analysis. These measures include the value of recreation and quality of life provided by green urban areas (COWI, 2012).

Although there is a substantial body of knowledge available to assist the implementation of adaptation measures, many cities have no or limited capacities to absorb that knowledge and transform it into targeted action. In Denmark, it is intended that all municipalities should have a climate change adaptation plan by 2013, but many of these cities lack the expertise to create these plans. The national government has therefore created an expert group which travels through the country and supports municipalities in developing local knowledge, learning from good practices, developing and mainstreaming adaptation action, and identifying and overcoming barriers ([17]). Also the European project 'Adaptation strategies for European cities' will support cities with exchange programmes, training and coaching ([18]).

Financing

The costs of adaptation measures vary greatly. Behaviour changes or mainstreaming adaptation actions into other policies can offer adaptation measures at very low cost. An increase of green urban areas to improve quality of life and wildlife in the city can at the same time help to reduce flooding and the effects of heat if designed properly. Adaptation can come as a co-benefit at no extra-cost, or it can drive certain measures to produce co-benefits itself. Other measures, particularly 'grey' infrastructure, like sewage systems, dykes, dams and desalination plants can be highly expensive and often exceed the financial capacity of cities.

Perhaps the most efficient way to encourage adaptation is to build resilience directly into urban design when renovating urban areas or building new ones (i.e. mainstreaming adaptation into urban planning). For example, the newly built Ørestad area of Copenhagen was not affected by the July 2011 flood, which was a 1-in-1 000-year event. This area has a sufficient number of open storm water systems, and a large number of areas that enable natural draining. Making changes to urban planning policy and avoiding urban sprawl into flood prone areas might be challenging to implement, but it can very efficiently reduce vulnerability. An even greater challenge in European cities is to climate-proof the older, already-built areas. As the Copenhagen example demonstrates, this requires a careful selection of measures.

Results/lessons learned

- Depending on their particular location and their design, cities are faced with a unique set of climate change challenges. Moreover, national legislation and culture give cities different powers in different Member States. Therefore European and national policy towards facilitating urban adaptation calls for a tailored territorial approach that recognises the specificities of regions and cities and their specific adaptation challenges and needs (e.g. ADEME, 2012).

([17]) http://www.klimatilpasning.dk/DA-DK/SERVICE/REJSEHOLD/Sider/Forside.aspx.
([18]) http://eucities-adapt.eu.

- The physical design of cities alters climate impacts, so urban design plays a key role in climate change adaptation. Integrating and mainstreaming climate resilience into the heart of urban planning and infrastructure renovation is an efficient way to reduce vulnerabilities in the long-term.

- Green infrastructure such as parks, gardens, trees, and green roofs and walls will be an increasingly important part of urban design. The planning and design of public and open spaces can help to increase air circulation and air quality in cities, limiting the heat island effect. Green infrastructure thus provides multiple services and functions that reduce vulnerability to climate change, contribute to mitigation and improve quality of life.

- Because of the strong inter-linkages between neighbouring urban areas and the often large financial costs of new investment, the implementation of urban adaptation requires coordinated and coherent multi-level governance.

- Capacity building and sharing expertise is a pressing requirement to help cities make progress in implementing adaptation.

Sources
COWI, 2012; EEA, 2010b; EEA, 2012b; Kazmierczak and Carter, 2010; Loftus, 2011; Philip, R., 2011; Schumacher, 2005.

2.5.5 Financing adaptation measures across Europe (Pan-European)

Adaptation goals
Supporting adaptation measures across Europe by providing financing as well as technical, operational and environmental advice.

Adaptation context
The European Investment Bank (EIB) — the EU's long-term financing institution — has made climate change mitigation and adaptation a top policy priority, supporting the EU's goal of low-carbon and climate-resilient growth within and outside the Union. Out of all the international financial institutions, it is one of the biggest providers of finance in this area: in 2011, the Bank invested EUR 18 bn in climate action, of which EUR 16 bn in the EU (30 % of the EIB's overall lending that year).

The EIB is working to identify and support climate-resilient projects that improve adaptation to climate change impacts. This work takes place within the framework of the EIB's sectoral lending policies and approaches, particularly those concerning energy; transport; water; wastewater; solid waste; forestry; and research, development and innovation. Climate change considerations are mainstreamed in all EIB sectoral policies and integrated into all operational activities. They are also systematically included in all EIB project appraisals to make the Bank's lending portfolio across all sectors more climate-friendly.

Adaptation actions
The Bank's commitment to ensuring the climate resilience of the projects it funds was established under its 2009 Statement of Environmental and Social Principles and Standards. Mainstreaming of adaptation in the EIB has focused on three key areas:

1. Internal awareness-raising
Internal efforts at the EIB have targeted the Bank's adaptation knowledge base. A number of sector specific Bank-wide seminars and dedicated workshops have been held. At these events, the Bank's sector experts and external speakers (including invited experts on specific issues, project promoters and consultants) have shared experiences of implementing climate adaptation measures, and discussed the challenges and best practices for introducing climate resilience as cost effectively as possible in each sector.

This work will continue, and the learning that has resulted will be disseminated, not only internally to improve the Bank's own work, but also through close work with DG CLIMA, the EU Financing Institutions (FIs) working group on Adaptation to Climate Change (EUFIWACC), other multilateral development banks (MDBs), and the climate consultancy community.

2. Increasing the resilience of projects
The Bank's sector experts have worked on increasing the resilience to climate change of the projects the Bank finances. Work to date has involved a review and documentation of sector-specific climate change risks, and work on internal guidelines. The purpose of the guidelines is to ensure that the Bank is systematically requesting information from borrowers regarding the climate risks and other risks the projects face.

To support borrowers in assessing climate risks, the Bank is piloting the use of technical assistance (TA) funds on selected projects to carry out vulnerability assessments and to identify 'no-regret' measures.

It has been demonstrated that identifying the necessary actions and measures at the planning stage is far more cost-effective than implementing them retrospectively. This process of assessing the vulnerability of the system or network within which a project is proposed allows for adaptation to take the form of 'soft' changes such as amended maintenance regimes, or operating standards. The EIB will remain engaged in the various funds being established for this purpose and in using existing and future TA funds to support borrowers in their vulnerability assessments and their preparation of resilient projects.

3. Financing and accounting for adaptation
To date, the majority of the Bank's adaptation financing has focused on water-related projects — e.g. water supply, flood protection and coastal protection. In addition to these, several operations have been financed that focus on improved forest management and protection such as reducing forest fire risk and improving fire-fighting capacity; rehabilitating burned areas; and tackling erosion. The project types are similar to those financed and reported by other IFIs (International Financial Institutions).

In addition to this group of projects, the Bank is working closely with other European FIs and DG-CLIMA on developing a consistent accounting system for tracking adaptation financing.

Several examples of recent investments and activities financed by the European Investment Bank are described below.

Accelerated Flood Prevention — Czech Republic
The Czech Republic was badly hit by six disastrous floods in the last decade, resulting in approximately 100 causalities and damage estimated at EUR 5 bn. A national flood prevention strategy covering the period 2002–2012 aims to increase protection for over 800 000 people and key infrastructure. Via loan financing, the EIB is providing EUR 360 m of the total programme costs of EUR 750 m. The Bank also brings added value through its input during the preparation and implementation of the schemes and through its environmental due diligence.

Port of Rotterdam — Netherlands
The expansion project will provide the port with nearly 1000 hectares of new port facilities directly on the North Sea. The project, which is expected to be completed by 2025, will accommodate continued traffic growth and contribute to improved transport links both within and outside the European Union. The reclaimed land will include road and rail access, harbour basins, and 5 km of quayside. It will also be protected by 12 km of seawalls, all of which have been designed to counter future climate change impacts including sea-level rise and increased storm surges. The port of Rotterdam will therefore be able to provide climate-resilient harbour facilities for the world's largest ships. The EIB is supporting this project with EUR 900 m of funding.

St. Petersburg flood barrier — Russia
The 25 km-long flood barrier at the mouth of the river Neva protects the City of St. Petersburg and its five million inhabitants. Designed to cope with floods of a 1 000-year return period, the mobile barrier helps to address a major threat that has plagued the city since its foundation and with increased frequency over the last decades. With a total cost of more than EUR 500 m, this is one of the world's largest flood protection structures. The EIB is not only co-financing the project with EUR 40 m, but it is also providing advice on technical, operational and environmental aspects.

Forestry

Afforestation and erosion control — Turkey
The EIB is financing the afforestation, erosion control, rangeland rehabilitation, and forest fire fighting activities carried out by the Turkish Ministry of Environment and Forestry (MoEF) with a EUR 150 m loan. This countrywide project covers the three-year period 2011–2013. Both wind- and water-based soil erosion are severe problems in many areas of the country, and this is likely to be exacerbated by climate change due to the increased incidence of droughts on the one hand, and intense precipitation on the other. Taking action to protect and restore soil fertility, and to reduce landslides and flood risks, has become a national priority. The investment funds i) the rehabilitation of some 70 000 hectares of degraded forest and 30 000 hectares of rangeland, ii) the afforestation of 100 000 hectares, and iii) the implementation of erosion control measures on 190 000 hectares. It also includes follow-up activities for 1.4 million hectares, as well as investments in forest infrastructure and fire-fighting equipment.

Environment and forests of Andalusia — Spain
The project comprises an integrated programme of investments, running from 2010 to 2014, aiming to improve the management of forests and nature reserves in the Spanish region of Andalusia. The EIB has invested EUR 200 m in the project, a key focus of which is the improved tackling of forest fires in the region. Climate change is associated with an

increase in both the number of 'fire risk days' per year, and the intensity of those fires that do break out. Adapting to this necessitates public investment in fire-fighting equipment and infrastructure. In addition to forest fire prevention and sustainable management of 164 000 ha of publicly-owned forests, the operation also includes nature reserve management and the establishment of 4 700 ha of new plantations. The investments are aimed at preserving the region's important natural heritage, improving its natural resources and mitigating the effects of climate change. The project will also be a source of job creation and help to boost economic activity in Andalusia.

Forests Framework Loan — Hungary
A EUR 200 m loan will co-finance selected elements of Hungary's European Commission-approved Rural Development Programme for the period 2007–2013. The operation will support EU objectives, in particular in the fields of climate change, forestry, biodiversity protection, and soil and water management. A key focus of the project is the establishment of new forest plantations on approximately 66 000 ha of land, targeting in particular the erosion-prone Great Plain region. Climate change is expected to further increase the existing erosion problems in Hungary, and well-planned afforestation on carefully chosen sites can be a very effective adaptation tool, as well as a means of improving the supply of timber biomass for a range of uses.

Administrative interactions
The EIB has been working closely with the European Commission (DG-CLIMA) and other IFIs through different working groups to ensure an integrated approach on the issue. The Bank was one of the founding members of the EU Financial Institutions working group on Adaptation to Climate Change (EUFIWACC). Since 2010, this working group has developed into a unique forum for practical exchanges on project adaptation work, definitions, methodologies, research, and tools. The Multilateral Development Bank working group on climate finance tracking has developed a common typology of sector-specific adaptation methodologies for measuring adaptation financing (see link below).

Results/lessons learned
To avoid maladaptation or making ill-informed decisions, it is important to consider adaptation as a process and to incorporate it into normal operational planning. Current and future climate impacts affect an organisation (or a project) in many different ways, and impact-reduction measures can take many forms.

Most of all, adaptation should be regarded as a matter of *good practice*. It is important to consider all risks that are posed to the project, and consequently increase the project's resilience by taking climate impacts into account in its design, management, standards, operation and planning. Finally it must be ensured that by improving the resilience of projects, the vulnerability of the surrounding communities or ecosystems is not increased.

Sources
European Investment Bank: http://www.eib.org/projects/topics/environment/climate-action/index.htm and http://www.eib.org/infocentre/press/news/all/eib-statement-of-environmental-and-social-principles-and-standards.htm;
Joint MDB Report on Adaptation Finance, 2011: http://www.eib.org/attachments/documents/joint_mdb_report_on_adaptation_finance_2011.pdf.

3 Policy context

Key messages

- Adaptation policy is being developed and coordinated at a number of governance levels, including EU-level, national-level, regional-level, and city-level. At present, EU-level adaptation policy is still mostly in the development phase. An adaptation White Paper was adopted in 2009, and this has served as a basis for the more comprehensive 2013 EU 'Strategy on Adaptation to Climate Change'.
- Although the Adaptation Strategy is still to be implemented, the EU has been using other initiatives as a vehicle to advance adaptation. The most important way this has been achieved is through 'mainstreaming', a process whereby adaptation is included in the EU's sectoral policies, such as agriculture, cohesion (e.g. infrastructure), environment (e.g. water, nature), and related funding mechanisms.
- Sixteen EEA member countries have already developed national adaptation strategies (nine more than in 2008) and 12 more countries are in the process of formulating adaptation plans. Fifteen EEA member countries have established web sites detailing adaptation challenges and actions in their countries. National adaptation strategies address primarily the water, agriculture and forestry, biodiversity, and human health sectors, while business, the economy, and regional development are hardly mentioned.
- However, even those countries that have adaptation strategies are not yet implementing adaptation measures in large numbers. Action at national level at this stage mostly comprises research programmes, mapping vulnerabilities, and planning. There is still a clear need to develop methods that would allow countries to monitor the progress of implementation and evaluate the effectiveness of action in the future.
- At national level, adaptation policy is formulated in different ways. Some countries adopt broad strategies, which are then supported by individual packages of legislation focusing on different policy areas, whereas other countries pass specific adaptation legislation. This diversity in policy approaches is mirrored in the diversity of adaptation challenges being faced by different countries. For example, some countries identify particular sectors such as water, agriculture, or forestry as being especially important for adaptation policy. Other countries rely on their regions to coordinate the implementation of adaptation measures.
- Adaptation policy is also being formulated at regional or local level. Cities are especially active in formulating adaptation plans as the effects of climate change are often felt most strongly in urban areas. Cities are focusing on specific problems of relevance to them, such as heat waves or flooding.
- The information provided by EEA member countries to the European Climate Adaptation Platform (Climate-ADAPT, http://climate-adapt.eea.europa.eu) gives an up-to-date overview of existing and planned adaptation initiatives. Countries have the opportunity to update their information on progress in adaptation on a voluntary basis and at regular intervals.

3.1 EU adaptation policy initiatives

3.1.1 Overview

In 2009, the EU adopted an Adaptation White Paper (EC, 2009a; further to the 2007 Green Paper on Adaptation (EC, 2007)), which supports the preparation of the 2013 EU Strategy on Adaptation to Climate Change. There are five main reasons that the EU decided to take action on climate change adaptation:

- Many climate change impacts and adaptation measures have cross-border dimensions;
- Climate change and adaptation affect EU policies;
- Solidarity mechanisms between European countries and regions might need to be strengthened because of climate change vulnerabilities and adaptation needs;

- EU programmes could complement Member State resources for adaptation;

- Economies of scale can be significant for research, information and data gathering, knowledge sharing, and capacity building.

The White Paper is structured so as to complement adaptation policies by Member States and ensure the coherence of all adaptation actions. It focuses on four pillars to reduce the EU's vulnerability and improve its resilience:

- To develop and improve the regional-level 'knowledge base' (assessments made using environmental data and information) on climate change impacts; vulnerabilities mapping; and the costs and benefits of adaptation measures. This will inform policies at all levels of decision-making;

- To integrate adaptation into the EU's sectoral policies, a process known as 'mainstreaming';

- To use a combination of policy instruments — market-based instruments, guidelines, and public-private partnerships — to ensure the effective delivery of adaptation;

- To work in partnership with Member States and strengthen international cooperation on adaptation by also 'mainstreaming' adaptation in the EU's external policies.

The EU aims to achieve these four goals using an approach that is coherent, flexible, and participatory. These styles of approach are relevant to all levels of governance and are explained in greater detail below:

- Coherent approaches (ensuring that policies all work to the same goal and that one policy objective is not undermining another)
  - strengthening the Knowledge Base;
  - 'top-down' strategies mainstreaming adaptation into the EU's sectoral policies and their instruments. Thus ensuring policy coherence;
  - ensure territorial and spatial cohesion through the regional and cohesion policy.

- Flexible approaches (making use of instruments/ methods that are appropriate for each situation)
  - using green infrastructure and ecosystem-based adaptation;
  - making use of 'adaptation pathways' that allow policymakers to adjust their plans if science, climate data or socio-economic developments also change;
  - using insurance, and economic and market-based instruments.

- Participatory approaches (seeking input from a wide variety of actors)
  - 'bottom-up' strategies building adaptive capacity (i.e. the ability of sectors, regions or communities to adjust to new conditions), and supporting the planning and implementation of adaptation actions;
  - working with multiple levels of governance (local, regional, national and European);
  - involving stakeholders, citizens and other non-governmental groups in the planning and implementation of adaptation measures.

Implementing the four goals according to these types of approach requires different policy tools. The tools that are available to the EU for adaptation are discussed in greater detail in Section 3.1.3.

In addition to these broad goals and approaches of the EU, adaptation policy is also discussed in a number of key EU initiatives, particularly 'Europe 2020 – Europe's growth strategy', the Resource Efficiency flagship initiative, and the European Commission's proposal for a 7th Environment Action Programme to 2020. These documents describe the current EU policy context for adaptation. They also give a broad vision for how businesses and governments can make the transition to a sustainable, resource-efficient, low-carbon and 'green' economy in Europe, where ecological resilience has been achieved. Achieving a green economy includes managing natural capital in a sustainable manner and protecting, conserving and enhancing ecosystem services and their resilience, for example through green infrastructure.

The EU 'Strategy for smart, sustainable and inclusive growth' ('Europe 2020 – Europe's growth strategy'), through its five headline targets and seven flagship initiatives, highlights the importance of mainstreaming and notes that 'We must strengthen our economies' resilience to climate risks, and our capacity for disaster prevention and response'. Adaptation also supports the overarching EU objectives of smart, sustainable and inclusive growth as stated in 'Europe 2020 – Europe's growth strategy'.

Adaptation is a cross-cutting issue and will affect key EU sectoral policies such as cohesion, agriculture, environment, disaster risk management, and related funding mechanisms. Many of the European Commission's services responsible for these

sectoral policies have already begun initiatives to include adaptation into their policy work. This set of initiatives was partly triggered by the European Commission 2009 Adaptation White Paper, and forms the context for the development of the 2013 EU Strategy on Adaptation to Climate Change (see more details in Section 3.1.2).

The strategy aims at addressing the threats and opportunities for adaptation actions for key sectors, regions and populations of Europe. Several aspects of the strategy are being discussed in a series of workshops with EU Member States, experts, and stakeholders from the private sector. An Adaptation Steering Group has been created, which consists of high-level representatives of EU Member States and environmental, business and other NGOs. The steering group is chaired by the European Commission (DG Climate Action) and has been regularly consulted about the development of the strategy. An online public consultation on 'Your Voice in Europe' was open for comments for all citizens and organisations from 21 May to 20 August 2012.

The European-level work on adaptation and the preparation of the EU Strategy on Adaptation to Climate Change were also supported by the launch early last year of the European Climate Adaptation Platform (Climate-ADAPT, http://climate-adapt.eea.europa.eu). Hosted by the European Environment Agency (EEA), Climate-ADAPT contains information on adaptation policy across Europe, and also includes adaptation case studies from across Europe and a number of software tools to facilitate accessing this information. Climate-ADAPT provides the EU entry point to information on adaptation and complements other knowledge generation and dissemination efforts being implemented or planned at national and sub-national levels. Climate-ADAPT will receive further information in the coming years from studies and projects initiated by the European Commission in 2011–2012, such as those examining adaptation policy in cities, or in the cohesion and CAP policies.

In addition, the revision of the Monitoring Mechanism Decision/Regulation ([19]) includes an article about reporting on adaptation actions by Member States every four years (aligned with the timings for reporting to the UNFCCC). The article requires Member States to report on their national adaptation planning and strategies, outlining their implemented or planned actions, the main objectives, and the climate-change impact category addressed. This revision will provide further information and data to Climate-ADAPT and will strengthen it as a critical source of information for policymakers across Europe.

The EU Strategy on Adaptation to Climate Change will consider adaptation actions within the European Union. Internationally, the EU remains committed within the United Nations Framework Convention on Climate Change (UNFCCC) to several political agreements (UNFCCC 2009 Copenhagen Accords ([20]), 2010 Cancun agreements (including the Cancun Adaptation Framework), 2011 Durban Platform for Enhanced Action ([21])) for:

- limiting the global mean temperature increase;
- recognising the need for enhanced action on adaptation to reduce vulnerability and build resilience in the most vulnerable developing countries through:
  - a comprehensive finance, technology and capacity-building support package;
  - long-term finance of USD100bn annually by 2020 to finance both adaptation and mitigation;
  - the establishment of a Green Climate Fund to this effect; and
  - a 'Fast Start' programme funded by USD 30 bn for 2010–2012;
- working on a roadmap towards a new legal framework by 2015 applicable to all Parties to the Convention.

The EU is also actively taking part in the Nairobi Work Programme (NWP ([22])) under the UNFCCC. The objective of the NWP is 'to assist all countries, but in particular developing countries, to improve their understanding and assessment of impacts, vulnerability and adaptation to climate change, and to make decisions on practical adaptation actions and measures on a sound scientific, technical and socio-economic basis'.

([19]) Adopted by the European Parliament in first reading on 12 March 2013 and expected to be adopted in the same wording by the next Environment Council in June (see http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-%2f%2fEP%2f%2fTEXT%2bTA%2bP7-TA-2013-0064%2b0%2bDOC%2bXML%2bV0%2f%2fEN&language=EN and http://register.consilium.europa.eu/pdf/en/13/st07/st07193.en13.pdf).

([20]) UNFCCC, 2009. Copenhagen Accord, 18 December 2009, UNFCCC Secretariat, Bonn, http://unfccc.int/meetings/copenhagen_dec_2009/items/5262.php.

([21]) http://unfccc.int/meetings/durban_nov_2011/meeting/6245/php/view/decisions.php.

([22]) http://unfccc.int/adaptation/nairobi_work_programme/items/3633.php.

Finally, EU Member States as well as the EU itself reported to the UNFCCC their '5th National Communications in 2010' with specific information on climate change impacts, vulnerability and adaptation ([23]).

3.1.2 Mainstreaming

Mainstreaming is a key pillar of the 2009 Adaptation White Paper. The Climate-ADAPT platform provides an up-to-date overview of the main initiatives for integrating adaptation into EU sector policies ([24]).

The Climate-ADAPT platform lists the main initiatives for mainstreaming adaptation in the following nine sectors: water management, marine and fisheries, coastal areas, agriculture and forestry, biodiversity, infrastructure, finance and insurance, disaster risk reduction, and health. This list is reproduced in Table A2.1 in Annex 2. The list also highlights the cross-sectoral and integrated nature of several policy initiatives such as Regional and Cohesion policy, and the Common Agricultural Policy. Inter-regional initiatives for coordinating mainstreaming of adaptation, such as the Alpine Convention (to which the EU is Contracting Party) and its Action Plan on Climate Change adopted in March 2009 ([25]), and the 2012 Alpine strategy for adaptation to climate change in the field of natural hazards ([26]), are not included in the table.

Mainstreaming initiatives in these nine sectors concentrate on the most vulnerable areas in Europe: the Arctic; northern, north-western and central-eastern Europe; the Mediterranean basin; cities and urban areas; mountain areas; coastal areas; areas prone to river floods; islands; and outermost regions).

Mainstreaming of adaptation is also a critical element of the EU's 2014–2020 Multi-annual Financial Framework (MFF; draft budget of EUR 960 bn). The MFF includes proposals for major funding policies and financial instruments, such as Structural Funds, the Cohesion Fund, the CAP (Common Agricultural Policy), TEN-T (Trans-European Transport Networks) and TEN-E (Trans-European Energy Networks), 'INTERREG' (the interregional cooperation programme), Life+, Horizon 2020 (the future research policy) and the legislative and non-legislative developments related to these. The draft includes a proposal to increase the share of climate-related expenditure (i.e. for climate change mitigation and adaptation as a whole) to at least 20 % of the EU budget (about EUR 190 bn of the overall budget) ([27]), with contributions to this 20 % figure coming from different budget lines of sectoral policy (such as cohesion policy, the CAP and energy and transport infrastructure) subject to impact assessment evidence. If implemented, the proposal will incentivise mainstreaming and coherence across policy areas (EEA, 2010b; see also Section 4.1). Within Horizon 2020, the share of climate-related expenditure is planned to be 35 %. The proposal will also lead to a large change in the amount of money dedicated to climate change adaptation and mitigation. Under the current 2007–2013 financial framework period, adaptation measures are estimated to have received approximately EUR 6 bn (0.6 % of the total budget of EUR 975 bn) stemming from risk prevention expenditures and other categories of expenditure where adaptation is integrated (Medarova-Bergstrom et al., 2011).

Cohesion policy is a particularly active sector for the mainstreaming of adaptation policy. The fact that cohesion policy addresses social cohesion, economic cohesion, and regional ([28]) cohesion makes it a cross-cutting policy area to begin with, and it is therefore especially relevant to adaptation mainstreaming. The European Commission has adopted a draft legislative package, which frames cohesion policy for the period 2014–2020, and proposes mechanisms to support climate-proofing investments. The new proposals are also designed to ensure that EU investment is strategically targeted on Europe's long-term goals for growth and jobs ('Europe 2020'). Climate change adaptation and 'risk prevention and management' (the term given to policies that prevent or respond to natural disasters) are specifically included as key objectives within the Cohesion Fund's environment field. However, the use of funding for climate change adaptation is not mandatory within that fund. One proposal linked

([23]) http://unfccc.int/national_reports/annex_i_natcom/submitted_natcom/items/4903.php.
([24]) http://climate-adapt.eea.europa.eu/web/guest/eu-sector-policy/general.
([25]) http://www.alpconv.org/en/ClimatePortal/Documents/AC_X_B6_en_new_fin.pdf.
([26]) http://www.planat.ch/en/marketing-materials-detail-view/datum/2013/01/03/alpine-strategy-for-adaptation-to-climate-change-in-the-field-of-natural-hazards.
([27]) http://ec.europa.eu/budget/reform.
([28]) The EU cohesion policy developed the concept of territorial cohesion in addition to social and economic cohesion (EU Green paper on territorial cohesion (EC, 2008)). It aims at addressing regional imbalances and therefore a territorial approach is important for a successful implementation and mainstreaming of climate change adaptation.

to the structural funds states that before any future spending projects are approved, a disaster risk assessment taking into account adaptation should be carried out to ensure that expensive and long-lasting infrastructure is able to cope with future climate change (EEA, 2012b; Medarova-Bergstrom et al., 2011). Under this proposal, the disbursement of funds would be made conditional on the completion of national and regional risk assessments. These assessments are critical to mainstreaming because the various EU cohesion policy funds target large and long-lasting investments and infrastructure, which represent large opportunities for implementing adaptation, but which could also possibly lead to significant maladaptation if they are not climate-proofed.

3.1.3 Adaptation 'levers' for EU action

This section aims at identifying how the European Union supports adaptation in practice. Key adaptation 'levers' (or policy tools) at EU level are identified in terms of instruments that the EU provides for each step in policymaking. This shows 'what', 'how', 'when' and 'where' the European Union supports adaptation, and 'who' is involved. Therefore this section maps EU support for adaptation rather than providing guidance on how to implement adaptation for each step of the policy cycle.

The section makes use of the adaptation policy cycle, a framework developed by the Climate-ADAPT platform's 'Adaptation Support Tool' to assist users in developing climate change adaptation policies ([29]). The cycle begins with the first step: to assess risks and vulnerability. The next steps are to identify and assess the adaptation options. The following step is to implement the action. This is followed by the last step, which is to monitor and evaluate the action. After this step, the cycle can begin again with a re-assessment of risks and vulnerability. The steps of this cycle can be re-considered periodically in order to ensure that adaptation decisions are based on up-to-date data, knowledge and policies. This iterative process will also allow monitoring and timely assessment of successes and failures and encourage adaptive management.

This section highlights the resources, tools and instruments provided by the EU for each of the steps in the adaptation policy cycle and can be accessed in greater detail on Climate-ADAPT.

'Assessing risks and vulnerability to climate change, opportunities and uncertainties' step

Tools and instruments the EU provides:

- EU Policy background:
  - Europe 2020 – Europe's growth strategy, Resource Efficiency flagship initiative, 2014–2020 Multi-annual Financial Framework (MFF), 7th Environment Action Programme to 2020;
  - EU Strategy on Adaptation to Climate Change, 2009 Adaptation White Paper, 2007 Adaptation Green Paper;
  - Rationale for adaptation at EU, national and sub-national levels;
  - European Commission – Directorate General's web sites (such as Climate Action, Environment, Agriculture and rural development, Regional policy, Humanitarian Aid & Civil Protection, Maritime Affairs and Fisheries, Health and Consumers Research and innovation).

- Financial support:
  - Overview of EU Instruments and Funds;
  - Instruments for Pre-Accession Assistance (IPA);
  - Neighbourhood policy (ENPI).

- Climate-ADAPT (EU entry point to adaptation knowledge base):
  - Access to data and information sources;
  - Scientific background (e.g. IPCC reports);
  - EU and national guidance for the development of adaptation policies;
  - National policy background;
  - Socio-economic and climate scenarios;
  - Risks, vulnerabilities and opportunities for EU sectors, regions and communities;
  - Key risks and vulnerability assessments from European, national and international organisations, e.g. FP4 to FP7 research projects, 'ESPON' (European Observation Network for Territorial Development and Cohesion) projects, INTERREG projects;
  - European Commission's service contracts on climate proofing for various sectors;

([29]) http://climate-adapt.eea.europa.eu/web/guest/adaptation-support-tool/step-1. The 'Adaptation Support Tool', which is a framework designed to guide and support adaptive management, borrows from the UKCIP policy cycle tool (http://www.ukcip.org.uk/wordpress/wp-content/PDFs/Risk.pdf, page 7), the UKCIP Adaptation Wizard and various other risk assessment frameworks, Willows and Connell, 2003.

- Information on how to identifying and deal with uncertainty in adaptation planning;
- Case studies and good practices;
- Overview of key organisations;
- Capacity-building support.

'Identifying adaptation options' step

Tools and instruments the EU provides:

- Climate-ADAPT (EU entry point to adaptation knowledge base):
  - EU and national database of case studies and implemented actions;
  - Generic grey, green and soft adaptation options in key EU sectors, regions and communities;
  - Illustration of good practices.

- European Commission's service contracts on climate proofing for various sectors;

- European Research Framework programmes.

'Assessing adaptation options' step

Tools and instruments the EU provides:

- Climate-ADAPT (EU entry point to adaptation knowledge base):
  - Access to data and information sources;
  - Case studies in EU vulnerable sector, regions or communities;
  - Planning /decision-support tools;
  - Methodological elements (e.g. costs/ benefits (economic, social or environmental) analysis).

- European Research Framework programmes.

'Implementation' step

Tools and instruments the EU provides:

- Information on key elements of implementation:
  - Instruments and related implementing provisions for sectors, regions and communities at stake;
  - Funds, including insurance:
    - Purpose of funds, availability and accessibility,
    - Process and procedures for application, conditionality and eligibility criteria,
    - How, who and when to get involved?,
    - Expected costs and benefits.
  - Implementing organisations, timeline and human resources;
  - Capacity-building, communication/ dissemination.

- Awareness-raising campaigns.

- Climate-ADAPT (EU-entry point to adaptation knowledge base):
  - Sectoral guidance;
  - Contact details of key stakeholders, implementing organisations (e.g. European Investment Bank) and counterparts at EU and national levels.

- Mainstreaming frameworks
  - EU Strategy on Adaptation to Climate Change;
  - 2014–2020 Multi-annual Financial Framework (MFF);
  - The EU Framework programme on research and innovation (Horizon 2020);
  - Cohesion Policy 2014–2020;
  - Common Agricultural Policy (CAP) reform;
  - Water Framework Directive (WFD);
  - Floods Directive;
  - Trans-European Networks for Transport and Energy (TEN-T, TEN-E).

- Implementing instruments and organisations
  - Operational Programmes and EU funds (Cohesion Policy);
  - 1st, 2nd and 3rd RBMPs (WFD);
  - Draft guidelines (TEN-T);
  - Risks maps (Floods Directive);
  - Life+ project;
  - Instruments for Pre-Accession Assistance (IPA);
  - Neighbourhood policy (ENPI).

'Monitoring and Evaluation' step

Tools and instruments the EU provides:

- Climate-ADAPT (EU-entry point to adaptation knowledge base):
  - Guidance and tools such as the Adaptation Support Tool for adaptive management and iterative processes that lead to monitoring and regular reviews of risks, opportunities, objectives and implementation plans;
  - EU Guidance for the development of national adaptation policies;
  - Country information and case studies that allow to learn from other initiatives;
  - Climate change impacts and vulnerability indicators/assessments;
  - Revision of the Monitoring Mechanism Decision (MMD);

- Frameworks for developing indicators supporting monitoring/measuring progress of process-based and outcome-based adaptation and policy efficiency/ effectiveness evaluation, e.g.:
  - Evaluation of Adaptation Strategy in Finland,
  - Reports on adaptation indicators report from the United Kingdom and Germany,
  - EEA/ETC-CCA Working Papers on Adaptation indicators),
  - Sectoral indicators (e.g. water).

3.2 National, transnational and sub-national adaptation actions

3.2.1 Comparative overview of national and sub-national adaptation policies

Action at national and regional levels ([30])
In recent years, several studies have been conducted on national adaptation policies in developed countries (Swart et al., 2009; Biesbroek et al., 2010; Preston et al., 2010; Dumollard, and Leseur, 2011; Ford et al., 2011; Greiving et al., 2011; EUROSAI-WGEA, 2012).

The following overview provides an up-to-date snapshot of adaptation policy among EEA member countries in 2012. It is based on the material submitted by countries in early 2012 to Climate-ADAPT according to a template that included the following headings: (1) Legal framework, (2) Assessments, (3) Priority sectors, (4) Local actions, (5) Summary table, and (6) Contact details. The submitted information is available here: http://climate-adapt.eea.europa.eu/web/guest/countries. Of the 32 EEA member countries, 28 have provided material to the platform. As this was the first time that EEA-wide information was collected, the information is partly uneven and therefore the findings should be treated as indicative. The actual adaptation strategies and policies of the member countries were not analysed in detail, as it would have required in-depth analysis beyond the submitted material.

According to the information submitted by the EEA member countries, a total of 16 countries have already adopted national adaptation strategies, and 12 others are currently in the process of developing them (Table 3.1). An adaptation strategy is generally understood to be a broad policy document that outlines the direction of action in which a country intends to move in order to adapt to climate change. Action plans are more detailed documents giving guidance on specific adaptation actions that are being planned. These action plans can cover adaptation actions generally or focus on certain sectors. The adoption of a strategy or action plan means that it has been endorsed by national government, published and is recognised as a policy document. However the legal status of these documents — and the extent to which they can enforce actions — varies between countries.

Most countries have initiated a range of activities related to adaptation. For example, research programmes on adaptation are being undertaken and national web portals related to adaptation are becoming more common. These research programmes can be funded nationally or regionally. Some are broad, supporting research on many aspects of adaptation, whereas others may be focused on a specific sector or sectors.

Large differences can also be identified in the coverage of the portals. Some provide broad sectoral information as well as guidance and links to various sources, organisations and local cases of adaptation. Other web portals are less broad, focusing more on mitigation than adaptation, or consisting mainly of one organisation's website to which has been added some rather general information on adaptation with little sectoral coverage. Of the countries that stated they had an online portal, Austria, Denmark, Finland, Germany, Norway, Sweden, Switzerland and the United Kingdom have portals with a broad coverage of adaptation, including sectoral information and examples of adaptation action at various levels of governance.

Similar variation can be observed in the way climate services are provided (climate services are essential data such as temperatures and precipitation, and are typically supplied by meteorological offices). The extent to which adaptation plays a role in these climate services differs from country to country, reinforcing the need for a pan-European overview.

In addition to the research programmes, policy documents and web portals, some countries have begun to work on ways to monitor and evaluate adaptation actions. Some of this work is focused on the development of progress indicators that could

([30]) For an analysis of regional climate change adaptation strategies and guidelines for their elaboration, see Ribeiro et al. (2009). The European Commission's DG Climate Action commissioned a study early 2013 on regional adaptation.

express some of the complexity of implementing adaptation (see also further details in Section 4.6). However, this process is only in its infancy, and official indicators of adaptation have not yet been established. Germany and the United Kingdom are the countries that are most advanced in their work on developing formal indicators to monitor progress in adaptation. Finland has chosen a slightly different route. It has reviewed its adaptation strategy, and requires government departments and agencies to monitor progress without using formally adopted indicators. Other approaches for monitoring and evaluation could also be valuable as alternatives to setting-up an indicator system, for example using existing monitoring systems in various sectors that already have a methodology in place.

Action at city level

A significant amount of the actions related to adaptation occur at the local level. City-level adaptation has been addressed in detail in the EEA report *Urban adaptation to climate change in Europe* (EEA, 2012b), which provides a wide range of examples of local adaptation action in various European countries. An overview of country initiatives is also available on Climate-ADAPT ([31]).

Table 3.1 Overview of adaptation policies in European countries. In total the EEA has 32 member countries, 28 of which have provided material for Climate-ADAPT (*)

Theme/topic	State			
	Adopted		**Under development**	**n/a**
National adaptation strategy	16 (AT, BE, CH, DE, DK, ES, FI, FR, HU, IE, LT, MT, NL, PT, SE, UK)		12 (BG, CY, CZ, EE, GR, IT, LV, NO, PL, RO, SK, SI)	
Action plans	14 (AT, BE, BG, DE, ES, FI, FR, HU, LT, NL, NO, PL, SE, UK)		18 (BE, BG, CH, CY, DK, EE, FR, GR, HU, IE, IT, LT, LV, PL, PT, SK, SI, UK)	2 (CZ, RO)
	Completed		**Being undertaken**	**n/a**
Impacts, vulnerability and adaptation assessments to support policy	17 (AT, BE, CH, CZ, DE, DK, ES, FI, FR, HU, LT, NL, NO, RO, PT, SE, UK)		15 (BE, BG, CY, CZ, DE, EE, GR, FR, HU, IE, IT, LV, PL, SI, SK)	
Research programmes	27 (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, IT, LT, LV, MT, NL, NO, PL, PT, RO, SE, SI, UK)			1 (SK)
	Online/established		**Under development**	
Climate services/ Met Office	25 (AT, BE, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GR, HU, IE, LT, LV, MT, NL, PL, PT, RO, SE, SI, SK, UK)		3 (BG, IT, NO)	
	Broad	**Less broad**	**Under development**	**n/a**
Web portal	8 (AT, CH, DE, DK, FI, NO, SE, UK)	7 (BE, FR, HU, LT, NL, PT, SI)	10 (BG, CY, ES, EE, GR, IE, IT, LT, LV, PL)	3 (CZ, RO, SK)
	Process in a rather advanced phase		**Process in an initial phase**	**n/a**
Monitoring, indicators, methodologies	2 (DE, UK)		24 (AT, BE, BG, CH, CY, CZ, DK, EE, ES, FI, FR, GR, HU, IE, IT, LT, LV, MT, NL, NO, PL, SK, SE, SI)	2 (PT, RO)

Note: (*) Note that the sum of a row does not necessarily equal the total number of countries as in some cases a country may appear in two state columns if part of the work is completed while other parts are still being developed or on-going (e.g. action plans). No information was available for Lichtenstein, Luxembourg, Iceland and Turkey.

Country codes (the acronyms follow Eurostat country codes (http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary: Country_codes; June 1 2012): Austria (AT), Belgium (BE), Bulgaria (BG), Switzerland (CH), Cyprus (CY), Czech Republic (CZ), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), Greece (GR), Hungary (HU), Ireland (IE), Iceland (IS), Italy (IT), Liechtenstein (LI), Lithuania (LT), Luxembourg (LU), Latvia (LV), Malta (MT), Netherlands (NL), Norway (NO), Poland (PL), Portugal (PT), Romania (RO), Sweden (SE), Slovenia (SI), Slovakia (SK), Turkey (TR), United Kingdom (UK).

([31]) The national profiles in Climate-ADAPT include many examples of local action: http://climate-adapt.eea.europa.eu/web/guest/countries.

In addition, the European Commission (DG CLIMA) is conducting a study on adaptation strategies for European cities, which will be published mid-2013.

There are many examples of cities in Europe that have adopted adaptation strategies or action plans, or are in the process of developing them. A majority of the local adaptation strategies reported to the EEA are comprehensive and address a broad range of sectors. A number of cities or city regions have also initiated specific measures. Many of these specific measures are part of existing climate strategies, and many cities have developed strategies that cover both mitigation and adaptation. For example, Dublin's climate change strategy includes adaptation objectives that initiate, modify and improve existing policies; and in Finland, several municipalities and regions have climate strategies that cover mainly mitigation, but also address adaptation to some extent. Surveys of local stakeholders also show that they find climate portals helpful in providing information, data, guidance, and examples of adaptation that assist them in implementing adaptation measures.

Several countries (for example France, Germany, Hungary, Norway, Romania, Spain and Switzerland) have cities that form collaborative networks of climate change mitigation and adaptation activities with other cities. An example from Norway is a six-year collaborative programme between the government and the country's 13 largest cities, 'The Cities of the Future' ([32]). Spain has created a Network of Cities for Climate (Red Española de Ciudades por el Clima – RECC) ([33]), which has produced guidance to help local authorities to promote adaptation and to identify vulnerabilities to climate change impacts. The purpose of these networks is to share experiences between cities and provide them with practical guidance on how to reduce their greenhouse gas emissions and how to adapt better to the impacts of climate change. Some of these networks have been created as a result of international projects, while some were initiated by national government bodies. These networks are not only comprised of local governments, they can also involve researchers or NGOs as partners. In France, Club ViTeCC is a network of local policymakers and scientists, initiated by CDC Climate Research, ONERC and Météo France. The aim of the network is to make the results of academic and applied research on the economics of climate change comprehensible and usable to local decision-makers and their service providers.

Some cities have developed or are in the process of developing sector-specific adaptation strategies and plans that concentrate on the most important vulnerabilities in the specific region. For example, Brussels is developing the 'Plan Pluie' rain plan; while Hungarian cities have plans for water management and are also creating alert systems in cases of high heat or UV risk. In Poland, four cities have flood risk reduction plans that also include plans for adaptation to climate change. In Estonia, several cities have developed adaptation action plans for storms and floods. Coastal cities such as Tallinn, Pärnu and Haapsalu, which have suffered most from these extreme weather events, have been the most active in implementing corresponding adaptation measures. In these cities, local monitoring and warning systems for floods and storms have also been developed.

Smaller-scale local adaptation projects and activities have also been initiated or planned. These concentrate on specific adaptation challenges such as reducing the heat-island effect in urban areas by designing green roofs, or improving water efficiency and supplying water to areas suffering from drought. For example, the Spanish city of Zaragoza has combined awareness-raising campaigns, voluntary commitments by citizens and businesses, and revised water tariffs in its Water Saving City programme (see further details in Section 2.5.4). The programme was initiated in 1996 by an NGO with support from the municipality. As a result, Zaragoza's water consumption decreased by nearly 30 % in 15 years, even as the population increased by 12 % in the same period. The key factors in making the programme a success were the active promotion of a water-saving culture, broad participation of stakeholders, and the establishment of a central coordination unit. In Amsterdam, an initiative called 'Watergraafsmeer' is bringing together water authorities, urban planners, housing organisations, and citizens to enhance adaptation in the water sector and promote water-related innovations in cities.

Trans-boundary and multilateral adaptation initiatives

In addition to national, regional and local level adaptation actions, countries or cities have also sought advice and support beyond their national borders. This has often taken the form of joint adaptation projects between several European countries or cities in different countries that seek

([32]) http://www.regjeringen.no/en/sub/framtidensbyer/cities-of-the-future-2.html?id=551422.
([33]) http://www.redciudadesclima.es/index.php.

to foster connections and exchange good practice between authorities. These projects are typically partly financed by EU-funds such as the Life+ and INTERREG programmes. INTERREG activities have been initiated in all regions in Europe. However most of them focus on north-west Europe and the Alps, while fewer adaptation projects address the Mediterranean, or eastern and south-eastern Europe. The projects differ in scope and focus as some are exclusively devoted to issues of adaptation, while others have a wider agenda in which adaptation to climate change plays an important role (details of transnational EU INTERREG projects are available on Climate-ADAPT at http://climate-adapt.eea.europa.eu/web/guest/transnational-regions). The Climate Change Observatory for the Pyrenees (OPCC) also provides examples of joint adaptation projects between several European countries or regions and cities in different countries.

The advantage of a regional focus is that it makes it possible to deal with region-specific issues of vulnerability and adaptation, such as changing conditions in mountain areas or in the Mediterranean. In the Alpine region for example, projects have dealt with a wide range of topics, from changes in natural hazards to infrastructure adaptation needs.

In the Baltic region, international adaptation-related projects include ASTRA (Developing Policies and Adaptation Strategies to Climate Change in the Baltic Sea; finalised in 2007) ([34]), which involved partners from six countries around the Baltic. Other international adaptation projects in the Baltic region include BaltCICA (Climate Change: Impacts, Costs and Adaptation in the Baltic Sea Region) and Baltadapt ([35]) ([36]). BaltCICA aims at preparing partner regions and municipalities to cope with a changing climate, while Baltadapt is a project to develop a Baltic-wide adaptation strategy that will focus on the adaptation challenges of the sea itself and its coastline. In the Mediterranean, CYPADAPT ([37]) is an EU Life+ funded project where partner organisations from Greece and Cyprus aim to produce a national adaptation strategy for Cyprus. The Italian-Greek-Spanish ACT project (funded by the EU's LIFE programme) ([38]) is a joint project between local authorities in these three countries. It aims at preparing local adaptation strategies in three cities (Ancona, Italy; Bullas, Spain and Patras, Greece). Another EU-funded project is 'Green and Blue Space Adaptation for Urban Areas and Eco Towns' (GRaBS), which involves 14 partner organisations from eight European countries ([39]). The aim of the project is to facilitate the exchange of knowledge and good practice on climate change adaptation strategies between local and regional authorities. In addition to these individual transnational joint projects, there are also important regional groupings of transnational projects such as SIC-adapt! ([40]) and C3-Alps ([41]). SIC-adapt! is a 'strategic initiative cluster' comprising eight transnational projects in northwest Europe, and C3-Alps is a cluster of Alps-based adaptation projects that promote knowledge sharing in the Alps-region.

Regional adaptation activities can also be part of broader regional organisations that do not have adaptation as their main focus. Examples include the 2011 EU Strategy for the Danube Region; the 2009 EU Strategy for the Baltic Sea Region; the Alpine Convention; the Carpathian Convention ([42]); and the Pyrenees Working Community (CTP)/Climate Change Observatory for the Pyrenees (OPCC) ([43]). All of these organisations, programmes and conventions are now seeing an increasingly important role for adaptation policy, and they provide a suitable framework for discussing adaptation issues and relating them to the broader context of regional cooperation (details of transnational strategic initiatives and programmes are available on Climate-ADAPT at http://climate-adapt.eea.europa.eu/web/guest/transnational-regions).

3.2.2 Governance and sectors identified

The policymaking approach

We have seen the diversity of governance levels involved in adaptation: European, national, regional, urban, and transnational. And this diversity in governance is mirrored in the diversity of policy approaches to adaptation regulation taken by

([34]) http://www.astra-project.org.
([35]) http://www.baltcica.org.
([36]) http://www.baltadapt.eu.
([37]) http://uest.ntua.gr/cypadapt.
([38]) http://www.actlife.eu/EN/index.xhtml.
([39]) http://www.grabs-eu.org.
([40]) http://www.sic-adapt.eu.
([41]) http://www.c3alps.eu.
([42]) See for example the CARPIVIA (Carpathian integrated assessment of vulnerability to climate change and ecosystem-based adaptation measures) project at http://www.carpivia.eu.
([43]) http://www.opcc-ctp.org.

countries across Europe ([44]). This section discusses this diversity in greater detail (see also Table 3.1).

Climate-ADAPT gives an overview of current adaptation-related legislation in European countries. Only a few countries have so far chosen to draft new legislation for dealing broadly with adaptation issues. In addition, countries are making changes to pre-existing sectoral legislation, effectively 'mainstreaming' adaptation at the national level. These revisions are not necessarily labelled as 'adaptation legislation' because their primary objective arises from different needs. However, such revisions may nevertheless make contributions to the implementation of, for example, national adaptation strategies.

Many mainstreaming initiatives in national sector legislation are driven by EU legislation that recognises adaptation. For example the Water Framework and Floods Directives have led to EU Member States making legislative changes that have taken into account the need to adapt to climate change.

There are four main approaches to the use of regulation in adaptation policies. One approach is for a country to use specific climate change legislation as the back bone of their regulatory system for adaptation. A second approach is for countries to instead use individual sectoral legislation on each adaptation policy area. A third approach avoids specific legislation, and instead adopts decisions in principle or formally approved national strategies; specific economic incentives; or supporting measures (e.g. 'capacity building' by increasing knowledge about climate change and adaptation measures among all stakeholders). A fourth approach is instead to adopt individual sectoral strategies.

It must be stressed that these four approaches are only ideal-types and are not mutually exclusive. In fact many countries combine elements of these four approaches. The relative merits (and disadvantages) of these different choices depend on the legal, administrative and political context of the countries. It must be stressed that the active involvement of public authorities in adaptation processes is relatively recent. The competencies of regional authorities also differ from country to country.

The United Kingdom has been a forerunner in developing climate change legislation. The Climate Change Act has been in force in the country since 2008. It creates a framework for enhancing the country's adaptive capacity, by requiring a statutory UK-wide Climate Change Risk Assessment (CCRA) to be undertaken every five years. The Act also gives the government specific powers such as requiring water and energy utilities to report on the actions they have taken to address the risks that climate change poses to their activities. To support its implementation, the Climate Change Act of the United Kingdom also established an Adaptation Sub-Committee (ASC) of the independent Climate Change Committee. In Scotland, a separate Climate Change Act has been in force since 2009. It requires the Scottish government to develop an Adaptation Programme that addresses the risks that have been identified for Scotland in the UK-wide Climate Change Risk Assessment (CCRA; DEFRA, 2011). The programme will be published in 2013.

In Germany there is no specific Climate Change Act, but instead relevant sector legislation is being identified and climate change legislative 'packages' have been developed that focus mainly on mitigation. The Adaptation Strategy of 2008 sets a general framework for adaptation activities and was developed jointly between the federal government and the German states (Länder). In Germany, the identification of relevant sector legislation has not yet been completed, although there are already some explicit references to adaptation in adopted laws (e.g. the Regional Planning Law, 2008, in connection with spatial planning; the Urban Development Planning Law, 2011, with regards to building codes; the Water Pollution Law, 2009, for water management).

In France, the Grenelle 1 Law (loi n° 2009-967, 3 August 2009), relating to the implementation of the Grenelle Environment Forum, made provision for 'the preparation of a National Adaptation Plan for a variety of areas of activity by 2011' (the French National Adaptation Strategy was adopted in 2006). The first National Adaptation Plan was published on 20 July 2011 and aims to present concrete measures designed to prepare for and exploit new climatic conditions in France. The Plan identified 20 key fields for action and covers a five-year period (2011–2015). Regional adaptation guidelines will be defined in Regional Climate, Air and Energy Schemes (SRCAE),

([44]) In this section, we understand regulation as any active involvement by state or sub-state authorities in directing an activity. The way that different countries, regions and cities approach adaptation regulation depends on their national regulatory framework, the specific needs and mandates of relevant authorities, and the general approaches used in the governance of the country.

and local adaptation actions will be designed within Territorial Climate-Energy Plans (PCET) under the provisions of Law 2010-788 of 12 July 2010.

In Switzerland, the revised CO_2-law, which entered into force on 1 January 2013, will be the legal basis for adaptation.

In Hungary, the Climate Change Act 2007 required that a national climate change strategy be prepared, and that National Climate Change Programmes (NCCP) be adopted every two years. In 2008 the country adopted a strategy addressing both mitigation and adaptation with a parliamentary decree.

Several countries are discussing — or are in the process of drafting — new adaptation-related legislation. In Norway, a White Paper on climate change adaptation is in preparation and will be presented to the parliament in 2013. The White Paper outlines national policies and guidance for adaptation in Norway. In Slovenia, the second draft of the National Climate Strategy was published in March 2012 and a final version is expected to be formally adopted. In Finland the need for specific climate change legislation was considered by the government in 2012.

In Belgium, existing sector legislation is expected to be revised to take adaptation concerns into account. In the Wallonia region of Belgium, the updated forestry legislation (Code Forestier) addresses climate change impacts on forests and promotes specific adaptation measures.

Many countries do not rely on legislation to promote the development of adaptation. They have opted not to create specific adaptation legislation, but instead to develop a national adaptation strategy. This strategy can frame and support the implementation of measures for adaptation by using (sometimes sector-specific) action plans; vulnerability assessments; research programmes; funding opportunities; and information services (Table 3.1). One example is Austria, where the government programme of 2007 required the development of such a strategy, which was eventually adopted in 2012. The Netherlands also adopted a series of decisions, the 'Delta decisions', which encompass water safety, the supply of freshwater, spatial planning, and management of the Rhine-Meuse-Scheldt delta ([45]).

National adaptation strategies are also supported in some countries by individual sectoral strategies or plans. For example France adopted an Integrated National Coastline Strategy (2012–2015) ([46]) and established the heat wave health plan ('Plan Canicule') as a result of the impacts on elderly caused by the summer 2003 heat wave. In Belgium, the federal government has developed the heat waves and ozone plan to cope with increased frequency of heat waves and ozone peaks. In Slovenia, an adaptation strategy for agriculture and forestry has been developed, including an action plan for 2010 and 2011.

Before concluding this section it must be stressed that creating legislation or strategies is only one part of the adaptation policy cycle. Another critical component is the evaluation and monitoring of these initiatives. The need for ex-post evaluations of the regulatory actions increases with the volume and the diversity of the regulation. So far few such evaluations have been done, with one exception being an evaluation that was recently begun in Finland. Germany and the United Kingdom also made progress in developing sets of criteria or indicators for defining, identifying, monitoring and evaluating 'good practices' (see further details in Section 4.3.1).

Sectors identified

Table 3.2 gives an overview of the policy sectors that have been identified in national adaptation policies in Europe according to the information submitted to Climate-ADAPT. Before proceeding further, it is necessary to stress that the procedures used by countries to collect and compile information for Climate-ADAPT differ from country to country. These procedures may therefore not have captured the full range of sectoral adaptation policies and measures. The submission of information to the platform was voluntary, and since this was one of the first attempts to obtain country-specific information, some incompleteness can be expected. The conclusions drawn in the rest of this section are therefore tentative and provisional.

In some countries, the identification and prioritisation processes have not yet been started. For example, the French national adaptation plan does not clearly prioritise any specific sector over others, as adaptation is a cross-cutting issue and sectors are often linked to each other. The plan lists 20 sectors with adaptation measures for each

([45]) http://www.government.nl/issues/water-management/delta-programme/delta-decisions.
([46]) http://www.developpement-durable.gouv.fr/IMG/12004_Strat%C3%A9gie-gestion-trait-de-cote-2012_V6_29-02-12_light.pdf.

of them. In Finland, the adaptation strategy has also a broad coverage of sectors, none of which is given specific priority. However, in spite of the lack of official priorities in the high-level Finnish strategy document, water resources management often features in on-the-ground Finnish adaptation policy. In Estonia the identification of policy sectors for which adaptation policy must be prepared is due to be carried out as part of the preparation of the country's national adaptation strategy. For this reason, Estonia is not included in Table 3.2.

But even in those countries where policy sectors have been identified, the work is not over. The process of identifying and prioritising vulnerable sectors is never complete, and priorities can change over time as more knowledge is acquired on each sector. Updated strategies may sometimes include new priorities, as in the case of the Czech Republic, where the upcoming adaptation strategy will include sectors that were not included in the current national adaptation programme.

The water sector is relatively advanced in implementing adaptation measures, and is often highlighted as a priority for further adaptation action, illustrating a positive feedback loop: sectors where adaptation issues are regarded as highly important and for which there is more information about climate change impacts are likely to go further in developing adaptation policies and actions. This in turn strengthens their position as national priority sectors. However, it is important that this positive feedback loop should not lead to other key sectors being ignored: sectors that are highly vulnerable but lack sufficient information should also be regarded as high priority so that comprehensive vulnerability and adaptation assessments are conducted.

The most commonly identified sectors (marked in green in Table 3.2) are: water management and water resources; forests and forestry; agriculture; biodiversity and ecosystems; and human health. Many of the sectors listed in Table 3.2 were also identified in other studies, including a detailed analysis of a sample of national adaptation strategies (Biesbroek et al., 2010 and a literature review of Ford et al., 2011). The second-most commonly identified sectors in Table 3.2 (marked in grey) include infrastructure, spatial and coastal planning, and also tourism. Those sectors that have only been identified in five countries or fewer are marked in blue.

The grouping of sectors differs between countries. For example, some countries regard the infrastructure category as comprising only buildings and 'grey' infrastructure (e.g. roads, railways, sewers, bridges, electricity plants), whereas other countries see infrastructure as a broader concept encompassing the built environment and 'green infrastructure'. This means that some specific issues, such as green infrastructure and urban green spaces, which appear to be identified by only a few, may actually be important for a broader range of countries. One interesting finding is that economic issues are practically missing from the list, with only two countries selecting the economy (Austria, Latvia) and four selecting business and services (Germany, Latvia, Spain and the United Kingdom). However, economic issues are also mentioned and included by some countries in other sectoral fields. This may reflect the fact that the implementation of adaptation policies and measures is still in its early stages, and that economic issues and the private sector have not yet been given much attention in existing adaptation policies. There is consequently a lack of information about adaptation measures being taken by the private sector. The exception to this is the insurance sector and the utilities sector, where available information on adaptation suggests that both industries are aware of the challenge and are taking action to respond to it ([47]).

Most of the identified sectors are relevant to lots of different regions of Europe and cannot be related to a certain geographical area. However, there are some vulnerable sectors that reflect the geographical conditions or economies of the country in question. For example, coastal zones and coastal management have been identified by Mediterranean countries, countries around the Baltic Sea and Ireland, while tourism (and other affected sectors, such as transport, which face the resulting 'knock-on' effects) has been identified by many countries in the Alpine, Pyrenean, Mediterranean and Central European regions. The identification of tourism as a sector could explain the small number of countries identifying economic issues as a separate category: tourism may be a good proxy category for economic issues. Desertification issues are one of the priorities in Spanish and Italian adaptation policies.

It should be noted that even if some sectors are identified in almost every country, the adaptation

([47]) Finance and insurance have often been identified in other studies (Biesbroek et al., 2010; BMVBS, 2010; Dumollard and Leseur, 2011) as a key sector for adaptation. The World Business Council for Sustainable Development (WBCSD), through its Electric utilities project, implements a work programme on adaptation, resilience and risks (2012–2014) that aims at providing information (e.g. Global Electricity Initiative, 2011), raising awareness and developing tools for the power sector to build resilient businesses.

challenges in that sector can vary significantly between different geographic areas. For example, the forestry sector in southern Europe faces increasing forest fires as a result of climate change, while forests in Nordic countries are more likely to suffer from problems such as storm damages and new pests. Thus, the content of adaptation policies — even under the same sector — can be very different in different countries. This is particularly relevant when framing pan-European efforts to promote adaptation to climate change.

3.2.3 Adaptation policy: taking stock and next steps

The material reported to Climate-ADAPT shows progress in strengthening the knowledge base (one of the objectives of the 2009 EU White Paper on Adaptation). In the case of adaptation, the knowledge base comprises primarily: assessments of climate change impacts and vulnerability; assessments of adaptation measures; the development of national adaptation strategies; the provision of climate services; and the creation of web portals (Table 3.1).

Table 3.2 Overview of sectors identified and addressed in national adaptation policies in Europe

Sectors	Number of countries mentioning sector	List of countries
Water management and water resources	23 countries	AT, BE, BG, CH, CY, CZ, DE, DK, ES, FI, FR, GR, HU, IE, IT, NL, NO, LV, PL, PT, SK, SI, UK
Forests and forestry	23 countries	AT, BE, BG, CH, CY, CZ, DE, DK, ES, FI, FR, GR, HU, IE, IT, LT, LV, PL, PT, RO, SK, SI, UK
Agriculture	22 countries	AT, BE, BG, CH, CY, CZ, DE, DK, ES, FI, FR, GR, HU, IE, IT, LV, PL, PT, RO, SK, SI, UK
Biodiversity, ecosystem services	19 countries	AT, CH, CY, CZ, DE, DK, ES, FI, FR, GR, HU, IE, IT, LT, NO, PL, PT, SK, UK
Human health and wellbeing	18 countries	AT, BE, CH, CZ, CY, DE, DK, ES, FI, FR, HU, IT, LT, PL, PT, SK, SI, UK
Infrastructure and built environment	14 countries	AT, CY, CZ, DE, DK, ES, FI, FR, IE, IT, HU, NO, PL, UK
Spatial planning, urban planning and development	14 countries	AT, CH, DK, GR, DE, ES, FI, FR, HU, IT, NL, PL, PT, UK
Energy, energy consumption	14 countries	AT, CH, CY, CZ, DE, DK, ES, FI, FR, IT, LT, PL, PT, UK
Coastal areas, coastal management	13 countries	BE, CY, DE, DK, ES, FR, GR, IE, IT, LT, LV, PL, PT
Tourism	13 countries	AT, CH, CY, CZ, DE, ES, FI, FR, HU, IT, PL, PT, UK
Civil protection, safety preparedness and rescue services	10 countries	AT, CZ, DE, DK, FR, GR, NL, LV, PT, UK
Transport, transport infrastructure	10 countries	AT, CZ, DE, ES, FI, FR, LT, NO, PL, UK
Fishery and aquaculture	9 countries	CY, DK, ES, FI, FR, IE, IT, PT, UK
Industry	8 countries	CZ, DE, ES, FI, FR, LT, PT, UK
Natural disasters/hazards	5 countries	AT, CH, FR, IT, SI
Soils and desertification	5 countries	BG, DE, ES, GR, IT
Business and services	4 countries	DE, ES, FI, LV, UK
Green infrastructure, urban green spaces	2 countries	AT, HU
Economy	2 countries	AT, LV
Regional development	2 countries	DE, HU
Communities	2 countries	FI, UK
Heat-related issues	1 country	BE
Mountain areas	1 country	ES

Note: Sectors are marked in different colours depending on how many countries have identified them in their adaptation policies.

One measure of progress in the building of the knowledge base can be seen in the growing number of national adaptation strategies. A study by Swart et al. (2009) reported the existence of nine national adaptation strategies in 2009, whereas Climate-ADAPT now shows 16 completed strategies and 12 additional ones being prepared. The identification of sectors (Table 3.2) also suggests that some mainstreaming is taking place. However, it must be noted that the information provided to Climate-ADAPT does not allow for any evaluation to be made of how successfully adaptation has been integrated into the policy areas. Nor does it give any indication of how adaptation costs and benefits have been addressed at country-level.

Climate-ADAPT provides examples of local adaptation policies and actions in various countries, but the available information does not specify if these are spontaneous 'bottom-up' actions, or if they are initiated/encouraged by 'top-down' long-term planning. More detailed information on the implementation of policy measures is needed before we can ascertain the precise relationship between local/regional adaptation actions and national-level planning. Such studies, when carried out in a comparative setting, could also contribute to transnational learning and cooperation as called for in the 2009 Adaptation White Paper and taken into account in the EU Strategy on Adaptation to Climate Change.

Therefore there is a clear need for further in-depth analysis of the adaptation information available at national, sub-national and local levels. The diversity of approaches to adaptation policy across countries reflects the different types of legal, administrative and planning systems. These legal, administrative and planning systems are key elements in policy planning and it would be helpful to have further analysis of their roles. Such an analysis would provide additional insights about the similarities and differences among European countries. These insights would be useful in considering the transferability of strategies, plans and actions for adaptation across countries, regions and cities (Newman and Thornley, 1996; Merryman and Pérez-Perdomo 2007; Firus et al., 2011a; Firus et al., 2011b; Charron et al., 2012).

Previous studies have identified the inability of adaptation policies to address important challenges such as the costs and benefits of adaptation measures; the policy instruments and funding mechanisms used to implement them; the monitoring and evaluation of implemented actions; and the factors for success in planning adaptation policies. These challenges are only partly addressed in national adaptation strategies. In the following paragraphs we look at three of these challenges. With respect to the issue of estimating costs and benefits, there is a variety of methods that can be used, and this issue is treated in greater detail in Section 4.3.5 (BMVBS, 2010).

Countries provided very limited information to Climate-ADAPT about the sort of policy instruments and funding mechanisms they intend to use (or are now using) to implement adaptation measures. The fact that adaptation action plans (Table 3.1) are being created, and that regional and local initiatives are being implemented imply that policy instruments are being used. However, there is no specific information on which policy instruments are being used. The fact that few countries have identified business and services, the economy, or regional development also suggests that public-private partnerships have not yet become a major area of development in the field of climate change adaptation. An in-depth analysis of the use of policy instruments would require more detailed information on the actual implementation of the adaptation policies and action programmes, as well as additional sector-specific analyses.

With respect to the issue of monitoring and evaluation, it must be noted that this is still a weak point in adaptation policy. There are also very few academic studies on this topic. There is therefore a need for more research-based and experience-based evaluations. There is also a need to develop monitoring indicators and evaluation criteria for assessing levels of preparedness. Based on the material in Climate-ADAPT, the process of developing monitoring and evaluation indicators has started in several European countries, even though the emphasis is still on monitoring climate change impacts rather than monitoring adaptation policies themselves (see further details in Section 4.3.1). Research-based evaluations are critical as they have an ability to enhance policy learning and improve the design of future adaptation policies and measures. Such evaluations would also provide opportunities to examine the persistence of some challenges of adaptation that previous studies have identified. For example, Ford et al. (2011) argue — based on a study of adaptation policies in developed countries, including non-European ones — that there is a mismatch between national statements concerning adaptation and local-level action. This mismatch seems to lead to adaptation interventions that aim at short-term risk reduction rather than long-term strategic planning — a mismatch that might impede future adaptation. In another study, Preston et al. (2010) conclude that the development of national adaptation strategies has many positive consequences, such as enabling capacity building;

identifying possible knowledge gaps and barriers to adaptation; and reducing societal and ecological vulnerability to both climate variability and climate change.

With respect to the factors for success in planning adaptation policies, previous studies (e.g. Biesbroek et al., 2010, Dumollard and Leseur 2011, Greiving et al., 2011) suggest that important factors include: compatibility between different sectoral policies (policy coherence); good cooperation between ministries, adequate research-based knowledge; the ability to enhance the capacity for both mitigation and adaptation simultaneously; and the involvement of key stakeholders in the process (see further details in Section 4.3.5).

4 Agenda-setting issues

Key messages

- Environmental and adaptation concerns should be further integrated into EU sectoral policies. This will ensure that sectoral policies are working towards compatible goals, and will improve the overall coherence of public policy. Coherence can also be supported by considering in greater detail a series of important new planning practices and tools that facilitate flexible and participatory approaches to adaptation.
- Flexibility is critically important in adaptation policy. It can be achieved by using so-called 'adaptive management' practices and adaptation pathways. These tools support decision-makers in designing flexible and robust measures in the face of deep uncertainty over future climate and socio-economic developments.
- It is also important that adaptation policy is supported by all levels of governance. Coordinated and coherent multi-level governance supports an integrated approach to adaptation, and bridges the gaps between the different levels of policy and decision-making. It also provides opportunities for ensuring further coherence of actions.
- There are also a number of important topics in adaptation policy that need further analytical work before they can fully inform adaptation planning. Examination of these topics leads to the following conclusions:
  - The monitoring and evaluation of adaptation policy would provide a regular overview of initiatives by countries and European bodies. This would support mutual learning and support the planning and implementation of adaptation in Europe.
  - The inter-dependencies of networks and systems (energy, water, transport, green infrastructure, information and communications technology) should also be further considered in adaptation planning so as to build resilience within European society.
  - When incremental adaptation is no longer sufficient, transformational adaptation may need to be implemented. Transformational adaptation involves managing radical change (including societal change) rather than protecting or restoring a certain environmental and social state. Transformational adaptation has implications at EU level: it is important to ensure the coherence of actions by the coordination of both transboundary issues and related financial resources.
  - The assessment of costs and benefits of adaptation actions at European, EEA member country and local levels is an emerging field of work. More work is needed before these considerations can fully inform adaptation decision-making.
- In future, the EEA will continue to support both adaptation decision-making across Europe and the implementation of the EU Strategy on Adaptation to Climate Change. It will focus its work on: providing the most up-to-date information and data in Europe at the European Climate Adaptation Platform (Climate-ADAPT); assessing the latest information and providing policymakers with analytical work that helps them plan and implement adaptation; and strengthening the knowledge base in areas that suffer from a deficit of information and assessments.

This chapter reviews a number of adaptation planning themes that would support further environmental integration and policy coherence, a topic which is first briefly addressed in the section below.

4.1 Towards more environmental integration and policy coherence

Coherent integration of environmental considerations across the many sectoral policy

domains will lead to progress being made across a number of targets rather than just individual targets (see EEA report *The European Environment — State and outlook 2010. Synthesis, 2010*). This will help to green the economy by reducing common pressures on the environment that originate from multiple sources.

Environmental policies have primarily influenced individual production processes and protected human health. They therefore only partly address today's systemic risks, which come from complex interlocking phenomena that go beyond single cause-and-effect relationships. These phenomena, such as over use of the land and oceans, originate from multiple sources and economic activities that compete for short-term benefits from resource exploitation. Often, multiple sources and economic activities interact to either enhance or counteract each other's environmental impacts. Taken together, they result in clusters of environmental pressures. Addressing such clusters can offer opportunities for more cost-efficient responses. In other cases, such clusters carry the threat that environmental action in one sector counteracts efforts done in another.

Reducing the pressures created by these phenomena will require cooperation between several domains to deliver coherent cross-sectoral and cost-effective outcomes that are in line with society's values and long-term interests and that also contribute to greening the economy.

The need to integrate environmental concerns into sectoral activities and other policy domains has long been acknowledged in EU policy, beginning with the Cardiff integration process in 1998. As a result, many EU-level policies explicitly take into account environmental considerations to some degree (e.g. the Common Transport Policy and the Common Agricultural Policy, for which reporting initiatives are established). Grouping together sectoral policies that are dependent on the same resources also has the potential for improved coherence in tackling common environmental challenges. More coherent policies across multiple sources of environmental pressures are also emerging. This marks a key difference compared to the situation 15 or 20 years ago, and provides a precedent for more effective collaboration between sectoral and environmental interests.

More integrated actions are a key objective of the 7th Environment Action Programme (EAP) proposal by the European Commission (EC, 2012), which calls for more policy coherence and greater integration of environmental issues into other sectoral policies.

Specifically, the EAP notes that although integrating environmental protection concerns into other EU policies and activities has been a Treaty requirement since 1997, the overall state of Europe's environment indicates that progress to date, while commendable in some areas, has not been sufficient to reverse all negative environmental trends. Achieving the EU's 2020 Strategy and related environmental objectives will demand even more effective integration of environmental and climate considerations into other policies, as well as more coherent, joined-up policy approaches that deliver multiple benefits. This should help to ensure that difficult trade-offs are managed early on in the design and planning phase, rather than in the implementation phase. It should also ensure that unavoidable impacts can be tackled more effectively. In this context, the provision of information on the implementation of EU environmental measures will be important.

The 7th EAP proposal notes also the importance of the Strategic Environmental Assessment Directive and the Environmental Impact Assessment Directive as effective tools for ensuring that environmental protection requirements are integrated in EU policy. It also stresses the role of local and regional authorities.

The 7th EAP proposal also highlights that the envisaged expansion of energy and transport networks, including offshore infrastructure, will need to be compatible with nature protection and climate adaptation needs and obligations. Incorporating green infrastructure into related plans and programmes can help overcome the fragmentation of habitats and preserve or restore ecological connectivity. This will enhance ecosystem resilience and thereby ensure the continued provision of ecosystem services that support both adaptation and mitigation objectives.

Finally, the 7th EAP proposal includes a number of priority objectives designed to support environmental integration and sustainability in the CAP (Common Agricultural Policy), CFP (Common Fisheries Policy), Trans-European Networks (TENs), and Cohesion policy reforms.

Similarly, efforts primarily intended to achieve environmental improvements should be designed to deliver co-benefits for other policies wherever possible. For instance, efforts to restore ecosystems can be targeted to benefit habitats and species and to sequester carbon dioxide, while improving the delivery of ecosystem services vital for many economic sectors, such as pollination or water purification for agriculture.

In the future, EU sectoral policies would benefit further from the broader use of established environmental accounting techniques. This would help integrated analysis of policy effectiveness, as well as of the environmental, economic, and social impacts related to adaptation measures.

4.2 Towards good practices for implementing adaptation

There is no commonly agreed set of criteria for identifying good practice in the implementation of adaptation policy. Nevertheless, there are several characteristics that are at least agreed to be important components of good practice. These characteristics are instrumental to the successful planning and implementation of adaptation in Europe. In the following two Sections, 4.2.1 and 4.2.2, we look at two of these characteristics in greater detail.

4.2.1 Flexible and forward-looking planning

Adaptation pathways and decision-making under uncertainty

Uncertainty is inherent to policymaking. Policymakers in Europe and elsewhere face deep uncertainties from a myriad of external factors, such as climate change, population growth, new technologies, and economic developments. Adaptation policy is no exception. In addition to these 'external' factors influencing adaptation policy, we must also consider other 'internal' influences on policy: societal preferences, stakeholders' interests, and stakeholders' evaluation of plans might also change over time (for historical examples, see Offermans, 2010 and van der Brugge et al., 2005). The end point is therefore not only determined by what is known or anticipated at present, but also by what will be experienced and learned as the future unfolds (Yohe, 1990), and by the policy responses to events (Haasnoot et al., 2012a).

Traditionally, policy planners have used models that assume incremental change in the environment and in the social and economic context. But the weaknesses of this approach are becoming more evident. Facing a deeply uncertain world, new policy approaches are needed to allow policy to adapt over time in response to how the future unfolds, what is learned about the system, and changes in the environment and society.

'Adaptation pathways' is the umbrella term given to the application of this flexible approach to adaptation policy. It seeks to encourage flexible but robust planning practices that avoid the 'lock-ins' that happen when policy is placed on an unchanging path as the result of a one-off adaptation decision that cannot be revisited. The adaptation pathways approach delivers a selection of adaptation options that can be called upon as some uncertainty about future climatic and socio-economic developments decrease and new uncertainty appears. The adaptation pathways approach is iterative, relying on constant updating by information flows that deliver additional resilience in decisions (see also Box 4.1). It stresses the importance of designing dynamic and flexible plans by creating a strategic vision of the future, committing to short and mid-term actions, and establishing a framework to guide future and longer-term actions.

The illustrative examples presented in Chapter 2 (Sections 2.5.2 and 2.5.3), show the development and implementation of an adaptation pathways approach, and provide a set of lessons learned that also help frame general guiding principles on adaptive management. It is critical for EU-level adaptation policy and governance to reflect upon these lessons.

The sections below give further details about the adaptation pathways approach and how it differs from other management practices that also incorporate at times iterative components (e.g. risk management).

Adaptation tipping points

The concept of 'tipping points' is crucially important to the adaptation pathways approach. Traditionally, climate change scenarios are taken as a starting point when defining strategies to adapt to the consequences of climate change. A projection of climate change is made and it might include forecasts for how changes will cascade through the environment. For example, a change in sea-level rise could have an effect on water quantity and quality, which could in turn affect human safety and agriculture (see Figure 4.1) (Kwadijk et al., 2010). Based on this projection, it is then possible to assess whether policy objectives would still be met with the current strategy or if an alternative strategy is needed.

The adaptation pathways approach recognises the uncertainties discussed above. By outlining numerous options and revisiting them frequently, better decisions can be made (e.g. taking the right decisions at the tight time, and avoiding maladaptation or lock-in into a particular technological, social, economic, political or

Box 4.1 What are adaptation pathways?

The adaptation pathway approach (also referred to at times as the 'route-map' approach or 'decision pathways' approach) is a new planning approach that has been developed to address deep uncertainties in policymaking processes and to design robustness into the adaptation strategy itself. Rather than taking an irreversible decision now about the one or two 'best' adaptation options to cope with climate change (which can lead to maladaptation and 'lock-ins' if the climate scenarios planned for do not emerge), it encourages decision-makers to postulate 'what if' outcomes and take a more flexible approach, where decisions are made over time to continuously adapt, while maintaining flexibility about future options (Jeuken and Reeder, 2011).

This aims at building flexibility into the adaptation strategy (rather than the individual measures) by sequencing the implementation of different measures over time, so that options are left open to deal with a range of possible different futures. This approach aims to ensure that whatever short- to medium-term plan is adopted, it is set in a framework that will not be maladaptive if climate change progresses at a rate that is different from what is predicted to be 'the most probable' today (Reeder and Ranger, 2011).

According to this approach, policymakers and planners facing deep uncertainty relating to climate change risks and socio-economic developments create a strategic vision of the future. They then commit to short- and mid-term actions, and establish a plan that can adapt over time to meet changing circumstances and ensure resilience in the long term (Albrechts, 2004; de Neufville and Odoni, 2003; Hallegatte, 2009; Lempert et al., 2003; Walker et al., 2001, Haasnoot et al., 2011; Kwakkel et al. 2010, Haasnoot et al., 2012b and 2012c).

The benefits of an adaptation pathways approach are directly correlated with the expense and potential degree of irreversibility of adaptation measures, such as with grey adaptation measures. However, the flexibility introduced by the approach is also of relevance to green and soft adaptation measures, which are also prone to irreversibility and are resource-intensive.

For further information about terminology and definition of key terms used in this field of work, see Kwakkel et al. (2011).

environmental path). However, the range of options in any scenario will not be available indefinitely. Some developments — whether they be social, environmental or economic — will shut off the possibility of certain responses. For example, a sea-defence barrier might be effective but only if sea levels rise by a certain amount. If sea levels rise more than anticipated, the barrier will no longer work. The moment that these developments occur are known as adaptation tipping points (ATPs). ATPs are defined by Kwadjik et al. (2010) in relation to water management as points where the magnitude of change due to climate change or sea-level rise is such that a strategy will no longer be able to meet its objectives. The ATP approach was first developed in the Netherlands in response to the publication of a new generation of climate scenarios.

The over-arching framework of the classical top-down approach addresses the question 'What if the climate changes or sea level rises according to a particular scenario?' The adaptation tipping points approach refines this question by asking 'How much climate change can we cope with and for how long will any given response be effective?' (see Figure 4.1). This means a shift in the framing of climate change adaptation from asking what the potential impacts of climate change are to asking what can be done and when (Werners et al., 2012).

The ATP approach addresses two key questions of policymakers: how long will the strategy be efficient (a measure of the robustness of a strategy), and how easy is it to change over time to an alternative strategy (a measure of the flexibility/low regret nature of a strategy)?

Reaching ATPs might have physical, ecological, technical, economic, societal or political causes. ATPs are the specific boundary conditions where technical, economic, spatial or socially acceptable limits are exceeded (Kwadijk et al., 2010). The time at which an ATP will occur defines the moment that alternative adaptation strategies/measures will be needed.

Within the adaptation tipping points approach, climate and socio-economic scenarios are used to define the moment in time when an ATP may occur. The occurrence of ATPs also depends on the characteristics of the system at stake (e.g. sector, region, community or country). For example, faced with the threat of flooding, the tipping point of a particular adaptation measure for the electricity infrastructure of a city may be different to the one for flora ecosystems in the same city. Conservative or risk-averse approaches adopt a pessimistic scenario, resulting in an earlier occurrence of an ATP in time, whereas risk-tolerant approaches can use an

optimistic scenario resulting in a later occurrence. The time range or interval between these two occurrences reflects the uncertainty expressed by the scenarios. This approach reduces the dependence of a decision on any single climate change scenario and therefore supports robust planning, and encourages adaptive and resilient approaches that have the potential to be cost-effective and avoid early maladaptation (Jeuken and Reeder, 2011).

Adaptation pathways and adaptive management

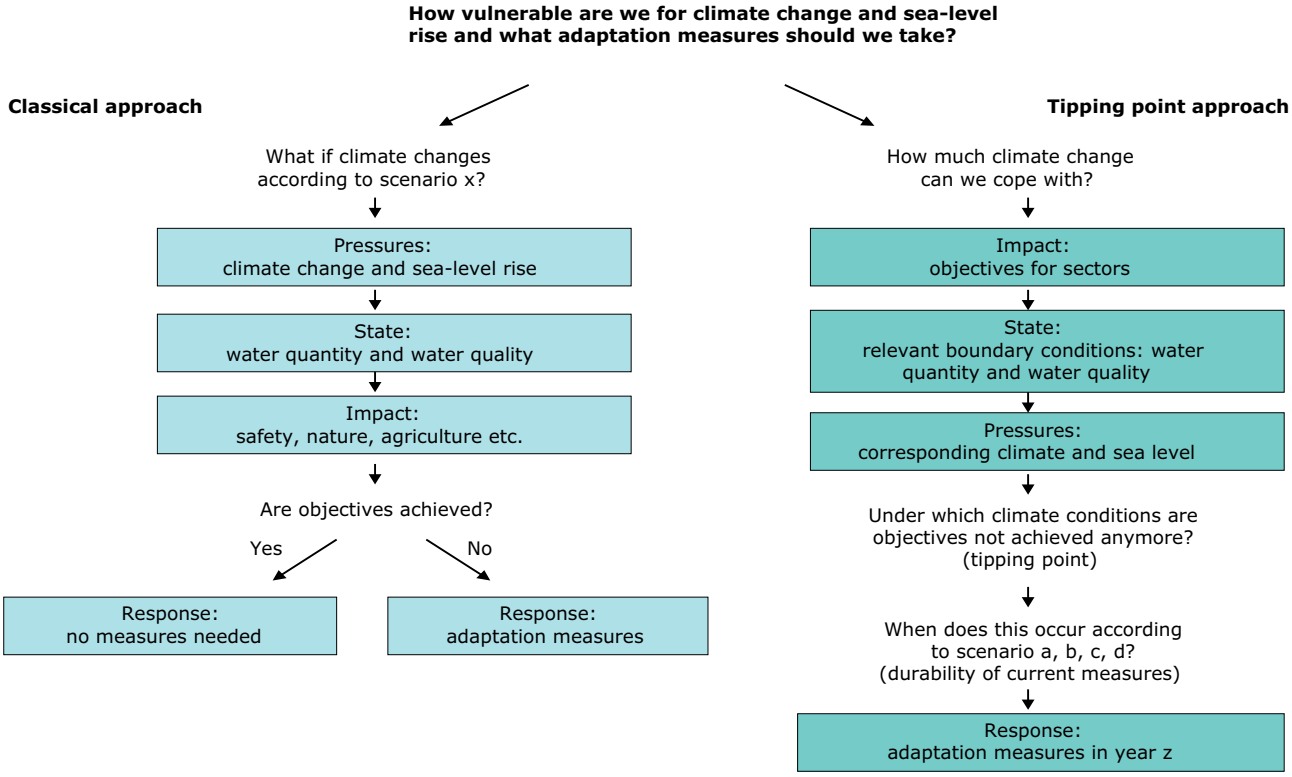
Adaptation pathways approaches support so-called 'adaptive management', a term that describes the ability to change plans based on new experience and insights (Pahl-Wostl et al., 2007). They provide insight into the sequencing of actions over time, potential lock-ins, and path dependencies (i.e. the tendency of new actions to follow similar patterns to previously implemented actions). As new information is available over time, monitoring the need for adjusting plans and actions is an important component of adaptation pathways approaches.

Adaptation pathways are illustrated in Figure 4.2 as a succession of alternative measures into the future. After an ATP has been reached (represented by a star in the diagram on the right of Figure 4.2), a new strategy is needed. This strategy, in turn, will have a new ATP. The construction of adaptation pathways is based on the performance of individual policy options (A, B, C) for a variety of possible futures (Haasnoot et al., 2012a).

The pathways are used to give information on the durability and timing of measures. They also show dead-ends, or — like in decision trees — the options remaining when a specific decision is made (Haasnoot et al., 2011).

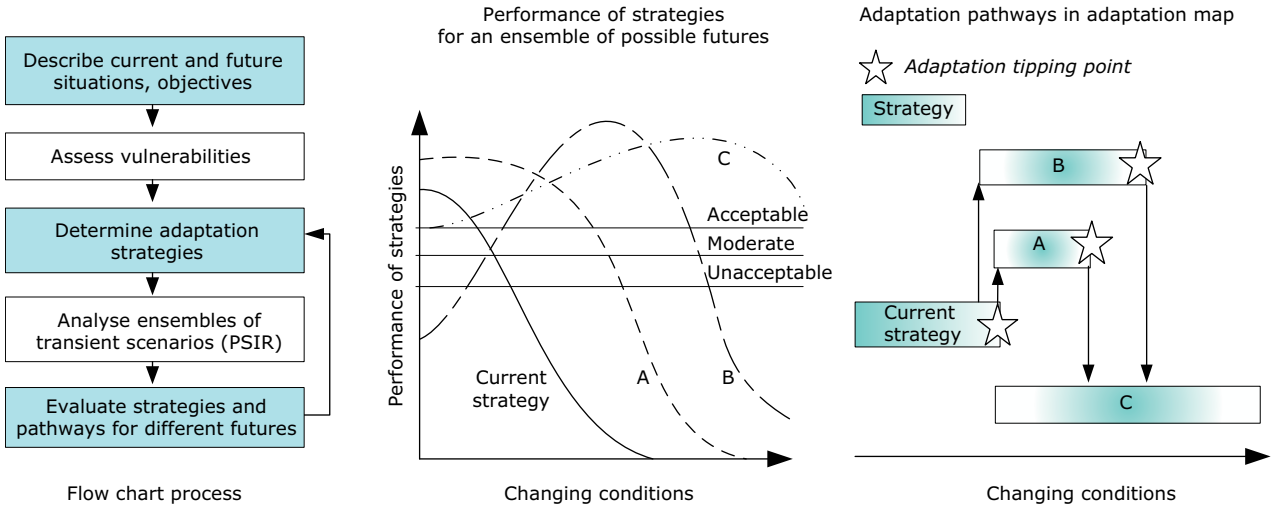
The adaptation pathways approach provides a useful tool for policymaking under deep uncertainty. While the illustrative examples of Chapter 2 (Sections 2.5.2 and 2.5.3) focus primarily on global climate change and the water domain, the adaptation pathways approach is generic and can be applied to most long-term environment-related decision-making problems, such as transportation, spatial planning, and business planning. The adaptation pathways approach is relevant for grey, green or soft adaptation actions. Green actions are

Figure 4.1 Classical 'What if' approach vs. 'Adaptation tipping points' approach



Source: Kwadijk et al., 2010.

Figure 4.2 Adaptation pathways: a succession of alternative measures



Source: Haasnoot et al., 2012a.

especially relevant in this respect: most ecosystems are inherently malleable and adaptable, so green infrastructure and ecosystem-based adaptation has the potential to provide flexibility in the face of changing needs and uncertainty about the future.

The EU FP7 MEDIATION (Methodology for Effective Decision-making on Impacts and AdaptaTION; http://mediation-project.eu/) project, in which adaptation tipping points are referred to as 'turning points'), explores further how tipping points shape decision-making and what needs to be taken into account in the design of adaptation measures (Werners et al., 2012). It also provides an additional set of examples in relation to biodiversity, agriculture and nature conservation.

The involvement of stakeholders (be it policymakers, citizens, industry organisations, or environmental NGOs) is also key to implement adaptive management practices effectively, and requires adequate resources and time. Decision-support tools that aim at making results of complex and heavy-to-run models more readily understandable are being developed to facilitate dialogue. This will better elicit the contribution of stakeholders to the development of adaptation strategies and strengthen the adaptive capacity of organisations. These tools typically help stakeholders to better understand uncertainties and how to plan for an uncertain future.

4.2.2 Multi-level governance

The previous Section 4.2.1, looked at flexibility as one of the key characteristics of successful adaptation policy. In this next section, we look at another key characteristic of successful adaptation policy: multi-level governance ([48]) ([49]). Multi-level governance relates to the so-called 'vertical' dimension of governance (i.e. governance from local level through to regional, national and European level). Although there are different types of multi-level governance, in this report, we follow the definition of Kohler-Koch and Rittberger (2006): 'non-hierarchical forms of policymaking, involving public authorities as well as private actors, who operate at different territorial levels, and who realise their interdependence'.

([48]) This section is mainly based on the 2012 EEA report *Urban adaptation to climate change in Europe — Challenges and opportunities for cities together with supportive national and European policies* (EEA, 2012b).

([49]) Multi-level governance relates closely to the EU principle of subsidiarity, which states that policymaking decisions should be made at the most decentralised level, in which a centralised governing body would not take action unless it is more effective than action taken at a lower government level. The principle of subsidiarity is closely bound up with the principle of proportionality, which requires that any action by the Union should not go beyond what is necessary to achieve the objectives of the Treaties. Multi-level governance refers more specifically to the need for the various levels of governance to coordinate their actions and ensure coherence.

Levels of decision-making
Adaptation to climate change in Europe is a task that concerns all governmental levels — from local to European. While municipalities and regions focus primarily on the implementation of location-specific adaptation measures, national governments and the EU usually provide a more strategic role, framing and supporting adaptation policy. Each of the governance levels has its specificities and limitations. It is therefore important to support the implementation of adaptation measures across different policy sectors and at different levels in a coordinated and coherent way. The remits of different levels of governance are a function of their legal and institutional context, which is itself a product of local, regional and national governments, as well as of the EU and wider global governance influences. This legal and institutional context can support the implementation of adaptation measures or hinder it.

The local level is often well placed to implement concrete adaptation responses to local impacts. Local conditions determine vulnerability and adaptive capacity, and local stakeholders know the specific conditions of their area very well, and can therefore devise flexible solutions using their knowledge. Many adaptation actions have emerged in recent years, and often without guidance or support from higher levels of government. For example, cities can implement structural measures such as the construction of parks, canals, ponds, thermal energy storage and modified sewerage systems. They can also play a role in the modification of street paving for water retention in existing urban areas or in encouraging better insulation and the use of green roofs.

Regional governments play an important role when adaptation issues exceed municipal boundaries, a phenomenon that makes it difficult for smaller and more local jurisdictions to adequately address the adaptation challenge. Hence a key role for regional governments is the coordination of spatial planning across municipal borders. Some measures supported beyond city borders can come at a lower cost, reduce the burden for each stakeholder, and be more sustainable than when individual local governments act separately. The specific role that regional governments can take depends on national structures for delegated ('devolved') competences, which can potentially create significant differences between regions. In order to assist regions to implement adaptation, some countries have established pan-regional adaptation networks. Germany's KlimaMoro (www.klimamoro.de) and Klimzug (www.klimzug.de) projects are examples of these networks.

National governments provide the crucial link between EU priorities on the one hand and local and regional adaptation actions on the other. National governments are particularly important in mainstreaming adaptation into national policies and in providing to stakeholders at national and sub-national levels the necessary background information on regional climate data, climate change scenarios, and decision-support tools. National governments are also important in providing guidance on how to set-up adaptation planning, assessments, and funding. Most importantly, national governments can provide a strategic framework (e.g. a national adaptation strategy) that embeds local and regional actions into the national context, and links cities and regions together. In this context national governments set a framework for developing climate-proof national legislation (mainstreaming, greening finance) and ensuring that national policies are coherent and supportive of local actions (Swart et al., 2009). In federal countries, multi-level governance can take the form of close cooperation between the national level (government) and the federal states, such as in Germany with the 'Bundesländer'. National governments are also uniquely capable of addressing issues of equity and fairness that arise from climate change impacts, ensuring that climate change policies link to regional development policies and address differences in vulnerability across different sectors and spatial divisions.

The role of the European level is described in detail in Chapter 3.

Table 4.1 further illustrates the multi-level governance of adaptation and the general role of each level (the European and national levels enabling adaptation, while the regional and local levels implement adaptation).

Challenges of multi-level governance
Each of these governance levels faces limitations in the effectiveness and efficiency of its adaptation actions:

- At the local level, there are important limitations that relate to the scale of intervention, as some measures (e.g. boosting green urban infrastructure) are local by nature and can be financially supported by municipalities on their own. However, other measures (e.g. addressing river flooding) require up-stream interventions, proper inter-municipal coordination, and often a regional or even national approach. The municipalities' efforts need to address issues of

Table 4.1 Actions at different governmental levels towards adaptation in Europe

Local action	Regional action	National action	European action
← **Implementing action**			
• Planning and implementation of local adaptation strategies • Mainstreaming of adaptation concerns into other policy areas • Spatial integration of adaptation needs through urban planning • Local emergency plans • Allocation of municipal resources and raising of other funds • Upgrading local infrastructure to make it resilient to climate change • Engaging civil society and private actors	• Providing incentives, funding and authorisation to enable local action • Addressing inter-municipal and urban-rural relations of climate change impacts and vulnerabilities • Developing and implementing with cities regional approaches, e.g. in river basins • Ensuring regional coherence of local /municipal plans and measures	• Providing a supportive national legal framework, e.g. appropriate building standards • Mainstreaming of urban adaptation into the different national policy areas and the national adaptation strategy • Funding of local adaptation measures • Providing national information related to climate change and regionally downscaled information • Funding of research and knowledge development for urban adaptation • Supporting boundary organisations that link science and policy to local adaptation needs • Adjusting the degree of decentralisation of competences and authorities	• Providing a supportive European legal framework • Mainstreaming of urban adaptation needs into the different European policy areas, e.g. cohesion policy • Funding of local adaptation measures as well as knowledge development for urban adaptation; • Providing European and global information related to climate change • Enabling and coordinating exchange of knowledge and experience across national borders • Addressing and coordinating cross-border adaptation issues
			Supporting action →

Source: EEA, 2012b.

regulation and financial support and thus need to encompass both horizontal cooperation with other municipalities and vertical cooperation with regional and state authorities.

- Although the local and national levels have so far received more attention in adaptation policy, more attention is now being paid to the regional level. However, the regional level can still suffer from limited influence (e.g. when the administrative region does not match the scale of the adaptation challenge, which might require a national or cross-boundary approach) or a lack of resources.

- The limitations of the national level are that the national focus of government action can sometimes undermine regional and local perspectives, making the national strategy less interesting or relevant for local actors. This seems to be a challenge in several European countries (e.g. Finland and Sweden), where local and regional adaptation strategies and measures may develop independently with little linkages to national adaptation strategies. There is a need to bridge the gap between local, regional (bottom-up adaptation) and national (top-down) strategies and actions.

- The subsidiarity principle guides the level of involvement of the European Union in local, regional and national adaptation, and a partnership approach and cooperative actions are needed. The various EU planning and funding mechanisms (e.g. the Cohesion Policy's Operational Programmes, CAP, and LIFE) need to be further implemented in relation to the identification of adaptation 'hotspots' (Swart et al., 2009). Mainstreaming of adaptation in EU policy remains an on-going task.

Supporting the implementation of adaptation measures across different policy sectors and at different levels in a coordinated and coherent way can therefore help to build bridges between stakeholders and different levels of government. No actor can resolve problems single-handedly. Each level of government has a role to play in supporting climate change adaptation.

Ensuring coordinated and coherent multi-level governance of adaptation in Europe requires a

consideration of the diversity of governmental systems within Europe (for more on this issue see the 'Legal and administrative families' framework relating to planning systems across European countries; Newman and Thornley, 1996). These systems determine to a large extent the ways in which local, regional and national authorities act, i.e. who does what, who decides, and who implements (Keskitalo, 2010a).

For example, in a more centralised country or administration, the local level is in general guided by the central or regional administrations. If adaptation is high on the national or regional agenda, legislation can ensure a minimum level of relevant action at the local level. However, a centralised state or administration that is not focused on adaptation may restrict possibilities for local governments to implement adaptation measures. In a more decentralised country, there will be little pressure from central government, and prioritisation of adaptation will depend on the sub-national authorities themselves.

Public authorities at national and sub-national levels also operate on a European level, for example through cooperation between the territories of the European Union. Examples of this cooperation include the European macroregional strategies of the Baltic Sea or the Danube (see Climate-ADAPT at http://climate-adapt.eea.europa.eu/web/guest/transnational-regions).

Coordinated and coherent multi-level governance is facilitated by a number of success factors that relate primarily to the ability of organisations to adjust their governance structures and procedures across levels of decision-making to address the specific needs of adaptation in terms of coordination, communication, and involvement of stakeholders. However it faces a number of structural, institutional and operational barriers. These barriers can hamper policy formulation, knowledge integration in decision support, decision-making, implementation, or monitoring and evaluation (EEA, 2012b).

Boxes 4.2 and 4.3 on the cities of Bratislava in Slovakia and Kalamaria in Greece (together with Chapter 2) provide illustrative examples of implemented adaptation actions across Europe that built upon multi-level governance. In these examples, the interplay of stakeholders and funding sources is a key factor for successful implementation.

The pillars of multi-level governance
The main pillars of multi-level governance are the following:

(a) policy coherence;

(b) territorial governance and spatial planning as a means for policy integration;

(c) building capacity across all levels of governance;

(d) securing access to funding for adaptation measures;

(e) developing the multi-level knowledge base.

In the rest of this subsection, we discuss briefly each of these pillars.

Actions can be implemented for each of these pillars by municipalities, regional and national governments, and the European Union. In order to further ensure the coordination and coherence of actions, it is important to involve stakeholders such as businesses, NGOs, the research community, and citizens (see also EEA, 2012b; The Governance of Adaptation to Climate Change (GoAdapt) project, http://www.wiso.boku.ac.at/go-adapt.html).

(a) A key challenge for the EU level of governance is to guarantee policy coherence by sectoral mainstreaming and by avoiding conflict between different sectoral policy actions. Flexibility needs to be built into the climate-proofing and mainstreaming processes. This flexibility can help deal with current uncertainties about future climate change and socio-economic developments, and can also accommodate new information on these over time. A key opportunity for incorporating this type of flexibility into European initiatives is the yet-to-be released guidance for integrating climate change and biodiversity concerns into the Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) Directives. This guidance needs to promote an adaptive management approach, where new information can be factored into climate-proofed processes.

(b) European resources, in particular the structural and cohesion funds, have shaped territorial policies across EU countries, and the financial requirements and evaluation procedures of these funds have influenced the way that regional governments work. Based on the identification of regional 'hotspots' for adaptation, the EU Territorial Agenda 2020 notes that the impacts of climate change vary considerably across Europe with different degrees of vulnerability and opportunities. The agenda further notes

that these challenges make it all the more important to coordinate from a territorial perspective policies on climate, energy, water management, agriculture, housing, tourism, and transport. Despite the growing acceptance of EU territorial governance, the process is still informal and depends on political priorities. Multi-level implementation is still at an early stage. Only a few Member States have adopted the territorial agenda and territorial governance approaches in their national level practices. In parallel, EU cohesion policy developed the concept of territorial cohesion ([50]) in addition to the more established concepts of social and economic cohesion (EU Green paper on territorial cohesion (EC, 2008); EEA, 2011). The implementation of the EU's 2014–2020 MFF will show how the concept of territorial cohesion — including a territorial approach to climate change adaptation — is put in practice.

(c) Climate change is a multi-level challenge that cannot be tackled at one administrative level only. Besides intergovernmental institutional linkages, there is a clear need for functioning communication channels between government authorities and private and public actors. This is necessary to coordinate climate adaptation and build institutional capacities across governance levels. Strengthening capacity building and creating communication channels may first require awareness raising, training, and the help of communication specialists. Networks of cities and regions can support this task. This work is important as studies show that the context within which information is shared determines to a large extent whether it will be used by stakeholders.

(d) The accessibility and mobilisation of EU funds is a crucial factor for promoting adaptation in a multi-level governance context. Securing access to funding means working across governance levels to access local, regional, national, and EU funding instruments. A range of funds is available for adaptation measures, including risk and disaster funds at the national level, and EU structural funds at the European level. These EU structural funds are often part of specific adaptation strategies and INTERREG projects at regional levels. It is important that these funds are disbursed in a way that removes all incentives for maladaptation. The proposed increase in the percentage of the EU budget earmarked for climate change to 20 % in the financial period of 2014–2020 will provide support in this context. In addition to public funds from the EU and national governments, it is also important to consider private investment. The private insurance industry has an especially important role here, as it is able to assess and communicate risk, spread costs through a variety of insurance products, encourage behavioural change through the price mechanism, and pool risk by accessing global financial markets.

(e) Knowledge is crucial in developing adaptation strategies and measures. Surveys have shown that local governments often do not have access to the best information about the impacts of climate change in their regions. Those local governments that do have access to this information often experience problems in understanding it. It is therefore essential to develop and share a multi-level knowledge base. It is also important to establish an active dialogue with authorities at different levels and with all stakeholders including scientific institutions. At the EU level, this knowledge base on adaptation is supported by the European Climate Adaptation Platform (Climate-ADAPT), together with key initiatives such as Research and INTERREG programmes, and the work of Science/Policy interface organisations (also referred to as 'boundary organisations'), which facilitate the communication and transfer of relevant data, information, and knowledge.

Stakeholder involvement is instrumental to decision-making practices across all pillars of multi-level governance. There are three levels of stakeholder inclusion: (1) Information sharing, (2) Consultation, and (3) Participation. The following steps are key to a successful process of stakeholder involvement:

- identify target groups (public, private, research, business and environmental NGOs, the education community, citizens groups);

- develop the involvement process, communicate its scope, and determine the underlying

([50]) Territorial cohesion is about ensuring the harmonious development of all regions in Europe and about making sure that their citizens are able to make the most of inherent features of these territories. As such, it is a means of transforming diversity into an asset that contributes to sustainable development of the entire EU.

rules (e.g. confidentiality, communication processes, sharing of documents) and objectives (e.g. developing a national adaptation policy, implementing/delivering adaptation);

- ensure the long-term involvement and commitment of key stakeholders and revise the composition of the target groups. Identify a key contact person in each stakeholder group who can facilitate communication during the whole process.

4.3 More analytical work needed

The previous Section 4.2 discussed some of the elements that have already been shown to contribute to successful adaptation policy. In this section we look at a number of issues that also appear to be important considerations for adaptation policy, but which have not yet been fully studied. These issues require additional analytical work before they can fully play a role in adaptation policy in Europe.

4.3.1 Monitoring and evaluation

Monitoring and evaluation (M&E) in adaptation is important because it allows us to learn whether adaptation measures are having the desired effect. Understanding what has gone well or not so well will help improve future outcomes of an adaptation action, for example by reducing the damage caused by climate change (including any lives lost), or increasing the number of green jobs that the adaptation action creates. This assessment work is vital because we are still at an early stage in understanding how best to adapt to climate variability; the impacts of climate change on environment, economy and society; and socio-economic developments. A monitoring system can support communication and the learning process (for example by identifying good practice, improving actions, avoiding maladaptation, and finding new opportunities (Harley and Van Minnen, 2009)), while an evaluation scheme can help indicate the progress towards meeting the goals of adaptation.

Measuring performance can be done in many ways. It can be compared with the intervention objectives, against a baseline ([51]), or against our emerging understanding of 'good adaptation'. These ways of measuring performance should not be considered mutually exclusive and can be used in combination. There is still much discussion about what constitutes 'good adaptation'. Some countries and organisations have provided guidance on this issue, including the UK's Department for Environment, Food and Rural

Box 4.2 Community network in Bratislava, Slovakia

While in some countries the main driving forces for the creation of an adaptation action plan are local authorities or local parliamentarians, in the Slovak case the plan was instigated by the non-governmental sector. The Regional Environmental Centre (a centre promoting cooperation and public participation in environmental decision making, and funded by national governments, the European Commission and private institutions) began by facilitating and moderating a network of local authorities and other non-governmental groups such as local communities. Although there was no formal agreement with the city of Bratislava, the network of community and government representatives became a full member of the official task groups preparing the Bratislava Strategic Development Plan, an urban planning strategy that considers adaptation concerns.

Photo: HatM

The network resulted in the active participation of environmental organisations, which led to improvements to the Strategic Development Plan. Climate change challenges and mitigation and adaptation issues were fully incorporated as priorities under the objectives of improving the quality of the environment and urban spaces.

Source: Hudeková and Tvrdoň, 2011.

([51]) A baseline is data that can be used as a reference against which future data can be compared. Establishing a baseline means that it is possible to track what has changed compared to before the intervention.

Box 4.3 Cross-departmental collaboration and external stakeholder involvement in Kalamaria, Greece

The Municipality of Kalamaria (Thessaloniki, Greece) has developed an adaptation action plan focusing on the use of green spaces. Before developing the action plan, strategic cooperation between different directorates and departments in the municipality was lacking. The municipality started with an internal SWOT analysis (strengths, weaknesses, opportunities and threats). It conducted interviews with the Department of the Land Registry Office and Municipal Property; the Department of Technical Works, Maintenance and Environment; the Planning Department; the Department of Greenery; and the Office of Protection of the Environment. The municipality then created a cross-departmental climate change-monitoring task force. This task force involved representatives from the Department of Technical Works, Maintenance and Environment; the Planning Department; the Programming Department; and the Civil Protection Department, and led to the development of an action plan with clear roles for all stakeholders. The task force will monitor and evaluate the implementation and then report to the mayor.

The adaptation action plan was also developed in collaboration with a number of external stakeholders. These included the region of Central Macedonia; the Union of the Municipalities of Thessaloniki, Kalamaria and others; 'Anatoliki' – a local government development company; the Aristotle University of Thessaloniki; various technical, transportation and planning bodies within Thessaloniki; the water company; and the fire service. The meetings resulted in concrete proposals for adaptation actions and how best to prioritise them. These proposals were synthesised and included in the adaptation action plan.

This cross-departmental and multi-stakeholder process brought different perspectives and types of experience to the adaptation action plan. They improved the understanding of climate change impacts among stakeholders and, as a co-benefit, helped to establish long-term collaboration that otherwise would not have taken place. The participants felt committed to sustaining the network following completion of the adaptation action plan.

... and Genoa, Italy
An adaptation action plan was developed by the local planning department in the province of Genoa, Liguria. In particular, the adaptation action plan concerns two practical projects aiming to balance development in the province with environmental vulnerabilities that may be exacerbated by climate change. To ensure successful delivery of the projects, the province of Genoa set up a multidisciplinary working team. It included representatives from the Department of Land and Basin Planning; the Department of Natural and Protected Areas; and the Department of Energy and Environment. The team was supported by two external experts in landscape planning and landscape design. This approach included differing viewpoints and helped to deliver a project that addresses both environmental vulnerability and climate change adaptation in a sustainable manner.

Source: Municipality of Kalamaria, 2011; Provincia di Genova, 2011; http://www.grabs-eu.org.

Affairs (Defra, 2010) and the EEA (Prutsch et al., 2010). The main points are summarised in Annex 3 of this report. As part of the preparation of the EU Strategy on Adaptation to Climate Change, there is currently a review of guidance documents across Europe, and EU guidance for the development of national adaptation policy processes might be made available in this Strategy.

Metrics and indicators: two different methods of measurement

It is helpful to consider the criteria against which progress can be measured, and these criteria could be metrics or indicators. Metrics (quantitative units) are attractive because they are objective, reproducible, and can be compared across projects and countries. However, they do not allow for monitoring of the context (the surrounding conditions in which the intervention takes place). Indicators can be either qualitative or quantitative and provide evidence about a certain condition. Indicators can either be 'process-based' (reflecting whether key stages of an adaptation process have been addressed) or 'outcome-based' (reflecting the effect of an adaptation action). Existing indicator systems (e.g. for sustainable development, environmental management, risk assessment or business continuity) can provide support in the establishment of M&E schemes for adaptation.

Examples of metrics for adaptation are challenging to find at this time mainly due to the long timescales involved in implementing an adaptation measure. However, there are good examples of metrics in other fields. For example, in the climate change mitigation field, CO_2 emissions are a very useful metric. These are quantitative, use a transparent and transferrable methodology, and can be compared year on year and between countries. Such metrics may be possible for adaptation interventions in the future, for example measures of water flow or quality that could help evaluate both high-flow situations linked to flood prevention interventions, and low-flow situations linked to the management of water abstraction measures. This metric would be attractive because this type of measurement is already in existence and would therefore provide a strong baseline against which to monitor change. In addition, there might

be a need to develop metrics that reflect multiple or cross-sectoral benefits of adaptation measures.

Indicators for adaptation are more developed than metrics. One example of a 'process-based' indicator is the Performance Indicator for Climate Change Adaptation (also known as NI188 ([52])) used in the United Kingdom. This indicator measured progress (through self-assessment) on assessing and managing climate risks and opportunities, and incorporating appropriate action into the strategic planning of local governments and their partners. The indicator aimed to ensure that local authorities were sufficiently prepared to manage the risks and opportunities that a changing climate presents to service delivery, the public, local communities, local infrastructure, businesses, and the natural environment. The possible risks and opportunities considered were: impacts to transport infrastructure from melting roads or buckling rails; increases in tourism; increased damage to buildings from storms; impacts on local ecosystems and biodiversity; scope to grow new crops; changing patterns of disease; impacts on planning and the local economy; and public health. The indicator worked by grouping local governments into one of five levels depending on how far they had advanced on adaptation. Each level could be either fully or partially completed. The levels were: Level 0: Getting started; Level 1: Public commitment and impact assessment; Level 2: Comprehensive risk assessment; Level 3: Comprehensive action plan; and Level 4: Implementation, monitoring and continuous review (LRAP, 2010). Local governments in the United Kingdom had submitted their progress according to this five-level indicator for many years, initially as a voluntary process, before it became a legal requirement for all local governments. Local governments are no longer obliged by law to submit their status according to this indicator due to a change in government.

Finland has also created an adaptation indicator. The country evaluated its National Adaptation Strategy (adopted in 2005) with both a mid-term review and (starting in 2013) a final evaluation. The mid-term evaluation assessed information on research that had been carried out, and identified new policy requirements. It also conducted a survey to see whether and how the indicative measures in the strategy had been launched and progressed in the sectors. The self-assessment survey used a preliminary indicator with five steps that detailed how advanced different economic sectors were according to four criteria: 'need for adaptation', 'impacts known', 'adaptation measures' and 'cross-sectoral cooperation'. The steps provide indicative information about progress. The results so far indicate that, averaged across all four criteria, most economic sectors are at Step 2, with agriculture, forestry, traffic and land use on Step 3. Water resources domain is the most advanced in terms of adaptation and is on Step 4. This type of 'process-based' qualitative indicator seems to work well for self-evaluation.

Germany is developing an updatable indicator system suitable for its national adaptation strategy (DAS; Schönthaler et al., 2010). Unlike the indicators that only deal with adaptation measures, these indicators deal with both the impacts of climate change and with adaptation measures across a range of so-called 'Action Fields' (13 sectors) and two cross-sectoral fields. Specifically, the indicators for the DAS should have a close link to the objectives and content of the political strategy. They should on the one hand highlight the main impacts of climate change on 'action fields' like forestry, human health, agriculture (that is, they will be 'impact indicators' based on existing data on past trends). On the other hand, the indicators will show measures that are under way to safeguard endangered systems (so-called 'response indicators'). Indicators for climate change impacts and indicators for adaptation responses will be closely linked to each other. The indicator system is intended to be primarily a tool employed at federal level in Germany. However, it is a nation-wide system and there are plans to link the system, both to the EU level and to the federal states (Länder). All government departments have been involved in the development of the indicator system. The Environment Department has the lead role in directing the overall process, and it relies on the active cooperation of and acceptance by all other government departments throughout the entire process — from selecting the indicators to preparing the report.

Challenges of monitoring and evaluation

Monitoring and evaluation in adaptation is particularly challenging for a number of reasons (Pringle, 2011):

- Coping with uncertainty: Uncertainty is an inherent attribute of any projections for the climate in the future. Inevitably, our understanding of climate science, impacts, and risks is dynamic. The result is that the 'goalposts' for adaptation M&E may appear to be continually

([52]) http://archive.defra.gov.uk/corporate/about/with/localgov/indicators/ni188.htm.

shifting, making it hard to establish appropriate objectives and measures.

- Dealing with long timescales: Significant time lags exist between adaptation interventions and measurable effects. The timescales over which the effectiveness of an adaptation action may need to be measured are such that there can be a substantial gap between taking action (or making an investment) and measureable effects (or the return on the investment).

- What would have happened anyway? The assessment of the appropriateness of an adaptation policy or intervention relies, to some extent, on our understanding of what would have happened without this action (the 'business-as-usual' scenario).

- Attribution: Attribution of the costs and benefits of adaptation interventions can be problematic. For example, long time lags mean that a variety of factors (such as socio-economic developments and natural hazards) and not just the adaptation intervention, may have shaped the outcomes. Furthermore, for sound reasons we are often encouraged to embed adaptation within existing processes and M&E systems, yet this can make attribution difficult.

- Identifying appropriate 'success' measures: An intervention that aids adaptation in one location or community may increase vulnerability or inequality elsewhere, raising the question of how to define success. Linked to this, adaptation interventions are often characterised by trade-offs, determined by assessments of risk. These assessments of risk recognise that accepting loss may be part of an adaptation strategy.

- Learning: M&E is not simply an opportunity to assess whether a project was economically justifiable or not. It is also an opportunity to learn so as to improve future measures. But how do we ensure that this learning informs future decision-making within a particular organisation or country, and how do we enable this learning to improve society's understanding of adaptation?

In what follows below, we list some guidelines for how best to ensure that critical lessons from adaptation measures are fully exploited:

- View adaptation as an iterative and informative process. Therefore it would be useful to use process indicators (as were used in the British and Finnish examples above) to determine whether progress is on track even if impacts cannot be determined yet.

- Consider how to assess whether the intervention has successfully retained flexibility and avoided 'lock-in' to a potentially mal-adaptive response.

- Establish a baseline that is appropriate and proportionate against which future progress will be measured. It is necessary to ensure that data for comparing individual indicators against the baseline will be available for as many years as possible into the future.

- Test the effectiveness of the chosen pathway against alternative assumptions for economic and environmental variables (e.g. adaptation pathways and adaptive management; see Section 4.2.1).

- Be aware that some interventions are multi-purpose. For example it could have goals that included adaptation, economic development and sustainable development.

- Ensure that there are both 'formative' evaluations ([53]) (i.e. evaluations made during the course of the project) and 'summative' evaluations (i.e. those made at the end of the project) to inform future decisions.

- Engage a wide range of groups in the design and delivery of the evaluation and gather feedback from these groups throughout the project. Evaluations that engage a wide range of stakeholders throughout the process are more likely to gain a complete picture of how different groups are vulnerable to climate change and how adaptation inventions can be made most relevant to their needs. It is also more likely that issues of social justice and unequal distribution of benefits (and harms) will be identified and can be addressed accordingly. Groups might include policymakers; project and programme staff; direct beneficiaries; and the wider community.

Monitoring and evaluation: lessons from development agencies

It can be helpful to consider the experience of

([53]) Formative evaluation focuses on ways of improving a project while it is happening. In contrast, summative evaluation seeks to judge the overall effectiveness of an intervention, usually after the project has ended.

development agencies in the monitoring and evaluation of adaptation measures. The work of development agencies is not necessarily targeted solely at adaptation measures. However, many of their projects contain an adaptation component, and this has led to interesting insights that could be of help to the broader adaptation community.

For example, development agencies have contributed to the debate on the role of qualitative data versus quantitative data in the monitoring and evaluation of adaptation. A recent OECD paper on M&E for development cooperation activities on adaptation recommends that M&E frameworks for adaptation should combine qualitative, quantitative and so-called 'binary' indicators (Lamhauge et al., 2012). It argues that on its own, any category of indicator is not enough. For instance, the development of a policy framework does not ensure its implementation and sustainability. It therefore needs to be complemented with quantitative indicators that for example measure the number of projects that have been implemented in response to the policy, or the number of households that have benefitted as a result. Qualitative indicators are needed to assess the change brought about by the policy. Such differentiation helps clarify the relative contribution of each activity towards the long-term objective. In some cases, surveys, focus group discussions, or other means of direct consultation with beneficiaries are needed in order to assess the level of change (Lamhauge et al., 2012).

Although the OECD paper is focused on interventions by development agencies in developing countries, the lessons learned have parallels with adaptation interventions in Europe. In the developed world, adaptation-specific initiatives and implementation are still recent, but development cooperation agencies have a long history in implementing projects and programmes with adaptation-related components.

With a few modifications, the existing frameworks used by development agencies for M&E of their projects could be well suited to perform M&E of adaptation-specific projects. The few modifications required include further defining adaptation, developing indicators and baselines, identifying milestones, and defining adaptation targets. The timing of monitoring and evaluation activities also needs to be adjusted to the longer time-horizon of many adaptation initiatives.

In the context of adaptation, this would mean complementing individual project and programme evaluations with overall monitoring and assessments of trends in the country's (and Europe's) vulnerability to climate change. A framework for linking individual assessments with national level assessments could help to broaden the focus from the means of achieving outcomes (individual interventions) to the desired end result (countries becoming less vulnerable to climate change). This would help highlight whether the overall level of action is sufficient, how the distribution of vulnerability is changing, and whether the composition of interventions is coherent.

Monitoring and evaluation in a European context

The implementation of the EU Strategy on Adaptation to Climate Change will benefit from monitoring and evaluation initiatives undertaken at national, regional or local levels. At the European level, it is important to have a regular overview of initiatives launched by countries and by European Commission services. In this context, the information provided by EEA member countries to Climate-ADAPT gives an up-to-date picture of existing and planned adaptation initiatives (28 countries out of a total of 32 reported information on a voluntary basis in 2011/2012). Countries will have the opportunity to update their information on a voluntary basis and at regular intervals in future versions of Climate-ADAPT. A comprehensive and in-depth analysis of the actual state-of-play of implementation of actions would be very helpful to have in future (beyond the information provided in Climate-ADAPT). In the absence of a common methodology, it would also be useful to have some evaluation of the progress and effectiveness of the different adaptation policies.

In addition, the revision of the Monitoring Mechanism Decision/Regulation ([54]) includes an article about reporting on adaptation actions by Member States every four years (aligned with the timings for reporting to the UNFCCC). The article requires Member States to report on their national adaptation planning and strategies, outlining their implemented or planned actions, the main objectives, and the climate-change impact category addressed. This revision will provide further information and

([54]) Adopted by the European Parliament in first reading on 12 March 2013 and expected to be adopted in the same wording by the next Environment Council in June (see http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-%2f%2fEP%2f%2fTEXT%2bTA%2bP7-TA-2013-0064%2b0%2bDOC%2bXML%2bV0%2f%2fEN&language=EN and http://register.consilium.europa.eu/pdf/en/13/st07/st07193.en13.pdf).

data to Climate-ADAPT and will strengthen it as a critical source of information for policymakers across Europe.

In addition, the OECD is preparing its Environmental Performance Review, and has recently consulted a number of European countries through a questionnaire on climate change adaptation and climate-related natural hazards. The Environmental Performance Review (to be discussed at the meeting of the OECD Working Party on Environmental Performance in June 2013 in Paris) will provide an independent assessment of countries' progress in achieving their domestic and international environmental policy commitments. It aims at identifying examples of good practice in stengthening environmental performance that could be helpful to other countries.

4.3.2 Interdependencies of networks and sectors

The interdependencies of networks and users is another issue that requires further study in order to better understand the role it can play in assisting or hindering adaptation. Adaptation usually takes place within a complex system, or even a system of systems such as a network. Examples of networks in which adaptation takes place include the urban environment with the many systems it contains. These systems include organisations, institutions and individuals, as well as green infrastructure, and 'grey' infrastructure for energy, water, transport, and communications. Adaptation that acknowledges and works with the constraints of this complex system will be more robust as it will have identified and responded to a comprehensive range of plausible risks. It will also be more likely to deliver spill-over benefits.

A change within one system can lead to significant disruption in other systems — what is known as a cascade failure. The change can originate from many sources, including climate change, climate variability, natural hazards, or social and economic changes.

A cascade failure would arise, for example, when extreme rainfall leads to flooding of the rail and road network, with resulting disruption to the movement of people and goods. This is likely to make it difficult for workers to reach their place of employment, which could affect important associated systems, such as the provision of health care or information and communication technology (ICT) services. A major disruption of ICT-services (as a knock-on effect, or as the direct consequence of flooding) would have feedback effects on transport too.

In the United Kingdom in 2009, in the Cumbria region of northwest England, the equivalent of one month's rain fell in 24 hours. This led to severe flooding, with six bridges being swept away (Horrocks et al., 2010). The flooding and loss of bridges not only affected road transport, but also telephone and electricity services, as these were carried over the bridges. Thousands of homes lost power and telephone connections, and mobile emergency communications stations were established temporarily (although five of these were also subsequently put out of action). Energy supplies to 1 200 homes were restored after nine days. In one instance, a new telecommunications cable, routed under the river to replace the one that had been carried by a bridge, was installed after seven days.

Disruptions that have cascading effects of this nature are likely to intensify as the impacts of climate change become evident. Those developing adaptation responses should be encouraged to take a broad perspective, taking into account the expertise of different groups in society that have experience of different systems. This will give adaptation measures a more comprehensive character, making them more than a simple response to a particular climate impact in a single sector or a specific location.

This comprehensive approach to interdependency has a number of advantages. They include:

- *Avoiding maladaptation* so that, for instance, a scheme to protect one community from flood damage does not increase the flood risks of other communities.

- *Challenging assumptions* in existing and developing adaptation plans. One such assumption is that a reliable electricity supply is necessary to supply potable water. But it will be necessary to ensure that the water supply network can continue to function in the event of power outages.

- *Identifying complementary issues* across otherwise separate themes, and also highlighting the barriers to adaptation that may arise unless there is coordinated action, for example in the case of floods and droughts that affect many people and organisations.

- *Early identification of areas of conflict* (e.g. managing demand for more limited resources) and areas of synergy (pooling of resources and expertise). Already, prolonged periods of drought highlight the competing demands for water from agriculture, power generation and domestic consumers.

- *Making effective use of resources* by, for example, collaborating and coordinating the involvement of stakeholders and sharing data resources.

- *Providing a more comprehensive view of the risks* associated with climate change, drawing in other relevant actors to establish how these risks relate to each other, and who (if anyone) has responsibility for them. A review of climate risks for a particular location may also indicate wider vulnerabilities, such as the location of critical national or international infrastructure (a major port or a rail line) or emergency facilities (e.g. hospitals).

The issue of interdependencies is mostly an emerging area of adaptation practice. As yet, there is little evidence and few examples of how to ensure that the question of interdependencies is considered in developing adaptation strategies and actions ([55]). However, some evidence is emerging in the area of critical infrastructure.

Research is now underway and will contribute to an understanding of interdependencies and how systems could respond ([56]). For example, the UK government commissioned a study in 2010 into infrastructure and adaptation, including consideration of interdependencies (URS Corporation, 2010).

Under the 'Knowledge for Climate' research programme, work is underway to look at the interdependencies in adaptation of infrastructure in the Netherlands. A mid-term report has been published (Maas et al., 2012), although work that assesses how links between the different infrastructure networks could lead to possible 'domino' effects will only be developed during the second stage of research.

Germany is investigating interdependencies between different economic sectors and climate change impacts based on integrated vulnerability assessments. On the federal level, a new methodology is being developed, which focuses on the energy system. It also looks at the forestry sector and its relation to the water system. In later stages of the study, other drivers of vulnerability beyond climate change will be considered, such as demographic changes, globalisation, and the availability of raw materials. The study will also look at different regions of Germany to assess the likely future impact and policy implications, for example in relation to regional planning.

Addressing interdependencies in adaptation practice should mostly rely on existing systems, procedures and processes, while adding to these an understanding of potential climate change impacts. EU sectoral policies offer opportunities for mainstreaming adaptation and thereby addressing interdependencies, for example in relation to the management of cross-border transport infrastructure. Climate change and interdependencies could also be integrated into the following existing management tools: environmental management systems, business continuity management, risk management, health and safety procedures, resource efficiency programmes, emergency planning regimes, quality assurance schemes, and disaster risk and recovery planning. These are processes that are already widely used across all organisations (public and private) in society.

The EU has initiated work that acknowledges the interdependencies in the systems that support our communities and economy. This work has focused primarily on critical infrastructure, energy and transport networks, and major-accident hazards of certain industrial activities. These include the Critical Infrastructure Directive 2008/114/EC ([57]), Trans-European Networks on transport and energy (TEN-T, TEN-E), the SEVESO Directives (2012/18/EU) and the DOMINO project (which models potential failures in linked systems and

([55]) There are at least two ways to approach the issue of adaptation and interdependencies:
— By looking at the response of at least two organisations (or sectors or actors) to one impact of climate change. Their responses can amplify the impact of that climate change. Thus, a decline in rainfall may have an impact on many actors who will all have claims to a more limited water resource. An adaptation response by one actor (e.g. abstraction from a local river) may have unintended negative consequences for the other actors. A coherent adaptation response will seek to be appropriate and acceptable to all stakeholders.
— By looking at the relationship between two or more factors which can increase or reduce the impact of climate change. For example, economic factors (declining incomes) could combine with climate change impacts (less summer rainfall and higher risks of heat waves) to decrease international summer tourism to the south of Europe and increase domestic tourism in the north of Europe. This could offer opportunities for local businesses, but also stretch the capacity of summer water resources in the north of Europe.

([56]) Examples of this research are: Infrastructure Transitions Research Consortium www.itrc.org.uk, Next Generation Infrastructures www.nextgenerationinfrastructures.eu, and SHOCK (NOT) HORROR http://research.ncl.ac.uk/shock.

([57]) Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection (Critical Infrastructure Directive), http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:345:0075:01:EN:HTML.

the relationships between different types of critical infrastructure) ([58]). These initiatives provide useful examples of addressing interdependencies and could be expanded both within the realm of infrastructure (perhaps to include ICT and water) and beyond. For example, it could be enlarged to consider public health and the provision of emergency services.

Across the EU policy landscape, it will be important to build on existing experience and action, in order to establish where there needs to be greater policy co-ordination and coherence. We risk maladaptation by failing to acknowledge critical links that exist between regions; economic sectors; ecosystems; and infrastructure networks that supply food, energy, transport, health, or other critical services.

4.3.3 Infrastructure and risk management

Infrastructure is another area of adaptation policy that requires further study.

The central role of infrastructure
Infrastructure is vital to the economy and the functioning of contemporary society (Table 4.2). In the coming decades, investment is required to ensure that infrastructure continues to deliver services to citizens and businesses (especially in cities and coastal areas). Upgrading and climate-proofing infrastructure is mainly a task that involves the built environment, such as bridges, roads, railways, water and electricity networks, and buildings. It will mean incorporating climate change adaptation concerns into building standards and retrofitting projects. Examples of this climate-proofing include: ensuring sewage systems can cope with heavy precipitation; reviewing building designs to improve energy efficiency; and adapting the energy grid, power generation facilities and transport system to be able to deal with extreme temperatures, water shortages or flooding.

In addition some countries have made assessments of the vulnerability of their critical infrastructure. For example, the United Kingdom has made an assessment of the vulnerability of its nuclear power plants to climate change (e.g. DEFRA, 2012a and 2012b) in connection with rising sea levels, flooding, storms and coastal erosion. This assessment has highlighted the need to take climate change impacts and natural hazards into account when planning or updating infrastructure. In 2009, Germany adopted a National Strategy for Critical Infrastructure Protection, which provides sector-specific information about how to deal with the vulnerability of infrastructure ([59]). This Strategy complements and strengthens efforts to mainstream adaptation into different sectoral policy areas. EUROCONTROL (2008, 2009, 2010 and 2011) has also addressed the vulnerability of Europe's aviation network to climate change and natural hazard.

These assessments all make clear that adaptation is a critical priority for our infrastructure. But it is not only formal studies that have made this obvious. European policymakers already have direct experience of how climate change and natural hazards can affect critical infrastructure. In the 2003 summer heat waves, French nuclear power plants in the Rhone valley were forced to shut down operations due to low water flows and high-water temperature, which affected the availability of cooling water for reactors. This obliged France to import more expensive power.

The challenge of updating and climate-proofing infrastructure is enormous. Infrastructure is present in almost every aspect of our lives, and new infrastructure is constantly being created. The challenge is made more complex by the potential double-sided nature of some infrastructure. For example, some infrastructure contributes to GHGs emissions (e.g. central heating networks). However, when planned correctly, infrastructure can also present opportunities to implement measures with co-benefits for mitigation and adaptation policies (e.g. building insulation). Infrastructure can also be a vector of maladaptation, although this is context-dependent (see Section 1.2). In many countries infrastructure is built or managed by government or semi-governmental bodies. However, private investors can also have a key financing role. The long-term nature of many adaptation actions makes them suitable for many types of investment manager (e.g. pension and insurance funds) seeking long-term investments.

'Although an increasing number of short- and long-term investors are now accustomed to including nonfinancial criteria in their equity and bond investment strategies, such criteria are still largely absent from the process of selecting long-term physical assets such as infrastructure,'

([58]) www.dominoproject.eu.
([59]) http://www.bbk.bund.de/EN/Topics/CriticalInfrastructureProtection/criticalinfrastructureprotection_node.html.

(Holm, 2010). Because infrastructure is characterised by its long life-cycles, it is at the same time particularly vulnerable to climate change and is expected to be directly affected — physically and financially — by the impact of these changes in the decades to come.

Transport infrastructure

A number of transport infrastructures are potentially at risk. Changes in climatic averages may lead to changes in transport infrastructure demand stemming from modified tourism flows (increasing flows to the north in the summer, with increases for the south in spring and winter) and from changes in agricultural production. Cochran (2009) focuses on transport infrastructure in France and its vulnerability to average and extreme climatic conditions (mean temperature and precipitation and extreme wind events). Most adaptation measures in transport infrastructure focus on changes to planning procedures and technical criteria to better adjust new infrastructure to a changing climate. Adaptation measures also typically focus on retrofitting existing infrastructure, and, in certain cases, the protection of existing infrastructure (Cochran, 2009). It is also important to take into account possible changes in demand, which would affect the use and profitability of infrastructure. Equally, it may be necessary to rethink concession-granting and the contracting of transport services and infrastructure maintenance so as to incentivise adaptation measures. In some cases, cost-benefit analysis may lead to the implementation of relatively low-cost 'soft' adaptation actions instead of expensive grey measures..

Part of the adaptation process in transport infrastructure will be the identification and prioritisation for reinforcement of critical network 'nodes' — the sensitive points in transport infrastructure (Cochran, 2009). Ensuring the robustness of these nodes may require the construction of 'redundant' systems for use in the case of failures in the day-to-day system. Thus, the retrofitting of existing infrastructure, and the design and construction of new infrastructure, will overlap with the need to develop protective redundancies at critical points in the transport networks. This may prove challenging, as new infrastructure development often requires substantial investment that, when channelled into the creation of necessary redundancies may be criticised as unnecessary in a time of budget streamlining and cuts.

Success in these efforts will depend on the ability of all stakeholders to develop and implement coherent approaches to the planning, construction, maintenance and operation of infrastructure. The relationships between actors can often impose a number of limitations on the ability to adapt (Reckien et al., 2009). 'Firstly, it is often difficult to disentangle hazards, impacts, and responsibilities

Table 4.2 Types of grey infrastructure by sector

'ECONOMIC' INFRASTRUCTURES					
Transport/ logistics	**Roads**	**Airports**	**Ports**	**Pipelines**	**Bridges**
	Railway networks		**Ferries**		**Tunnels**
Energy and Community services (utilities)	**Energy production**	**Natural gas** (distribution/storage)		**Electricity** (production/ distribution)	**Water** (distribution)
Communications	**Cable networks**	**Satellites**		**Transmission/broadcasting** (wireless network, radio waves, etc.)	
'SOCIAL' INFRASTUCTURES					
Health care infrastructures (hospital, etc.)	Waste (treatment)	Water (treatment/ distribution)	Housing	Leisure activities Education	Penitentiary infrastructures

Source: Holm, 2010.

in a way that fosters a clear framing of the issue and adaptation action. Second, the complex dependencies, assignment of responsibilities and the externalities involved often make non-action a rational behaviour even when convincing expert knowledge is available. Further, even in light of convincing evidence, long-established routines and habits can block the inclusion of changing environmental conditions and previsions into technical and decision-making processes' (Cochran, 2009).

Risk management and investment
To cope with climate risks, long-term investors can resort to insurance (Holm, 2010). However, although insurance is necessary, it is not sufficient because insurance companies have difficulty in estimating climate risk due to its inherent uncertainty. In addition, as certain climate risks become more certain, some insurance companies are simply declining to offer insurance (for example with buildings located close to the sea shore).

In the wake of the recent financial crisis and in the context of a global economic downturn, long-term investors are now showing interest in infrastructure as an alternative investment that can provide stable and sustainable revenue in the long term (Holm, 2010). To optimise the management of risks linked to climate change, long-term investors can choose to finance infrastructure that meets location, construction and operation criteria relative to climate change adaptation (and mitigation). Investors therefore need to incorporate climate change uncertainty and the ever-growing body of information on climate change impacts and vulnerabilities into their investment decision-making process. They therefore need to value at regular intervals the option of investing or postponing to later their investment in new infrastructure or retro-fitting current infrastructure. Taking into account the increasing availability of information on climate change is a good tool to ensure adaptive management and avoid as much as possible maladaptation. 'Low-regret' measures should be the starting point for implementing measures, particularly when they can accommodate progressive adjustments in future periods (e.g. raising dykes).

However, investing in adaptation strategies carries risks. For example, new technologies may be promising, but until they are deployed, it is impossible to estimate how well they will work. Other risks include the possibility of changes in the regulatory environment, or new information on climate change, which could make existing investments less profitable. All of these risks are potential barriers to investment (Holm, 2010). In the event that public authorities wished to mobilise private investors and channel their investment flows towards infrastructure suited to the new climate situation, it might be in their interest to take on some of the risks by introducing appropriate public guarantees (e.g. through public-private partnerships). This would allow them to attract private funds.

'The necessity for concerted action across a wide range of actors to proactively adapt to climate change poses a number of difficulties, as in many cases the costs and benefits of adaptation action are not evenly distributed' (Cochran, 2009). 'As is sometimes the case with mitigation actions, adaptation measures can also imply real costs to individuals or groups of actors, with benefits for the public good. As such, it may be difficult in many cases for proactive, autonomous adaptation measures to be put in place by individual actors without some form of incentive (positive or negative) from local or national authorities' (Cochran, 2009). This is the case for example with the transport sector, where even long-term concession granting may not be enough to induce proactive adaptation action by operators. There might also be moral hazards. For example, when the state acts as an insurer of last resort, it can act as a disincentive for private actors to properly hedge risk (see Box 4.5). It is therefore important in the first instance to encourage low-regret adaptation measures and other approaches that develop co-benefits. This approach is more likely to succeed in fostering action from all actors involved (Cochran, 2009).

4.3.4 Transformational adaptation: moving beyond coping

As more is known about changes in climate (including climate variability that occurs in the absence of climate change and extreme weather events) and the nature of adaptation measures required, there is an increased recognition that both 'incremental' and 'transformational' adaptation will be required (for definitions, see Box 4.6). The need to consider transformational adaptation has become even more pressing as experts have re-assessed the degree of adaptation that will likely be necessary: while it is recognised that we need to continue mitigation efforts to limit global temperature increases to 2 °C, it is also recognised that adaptation efforts should include

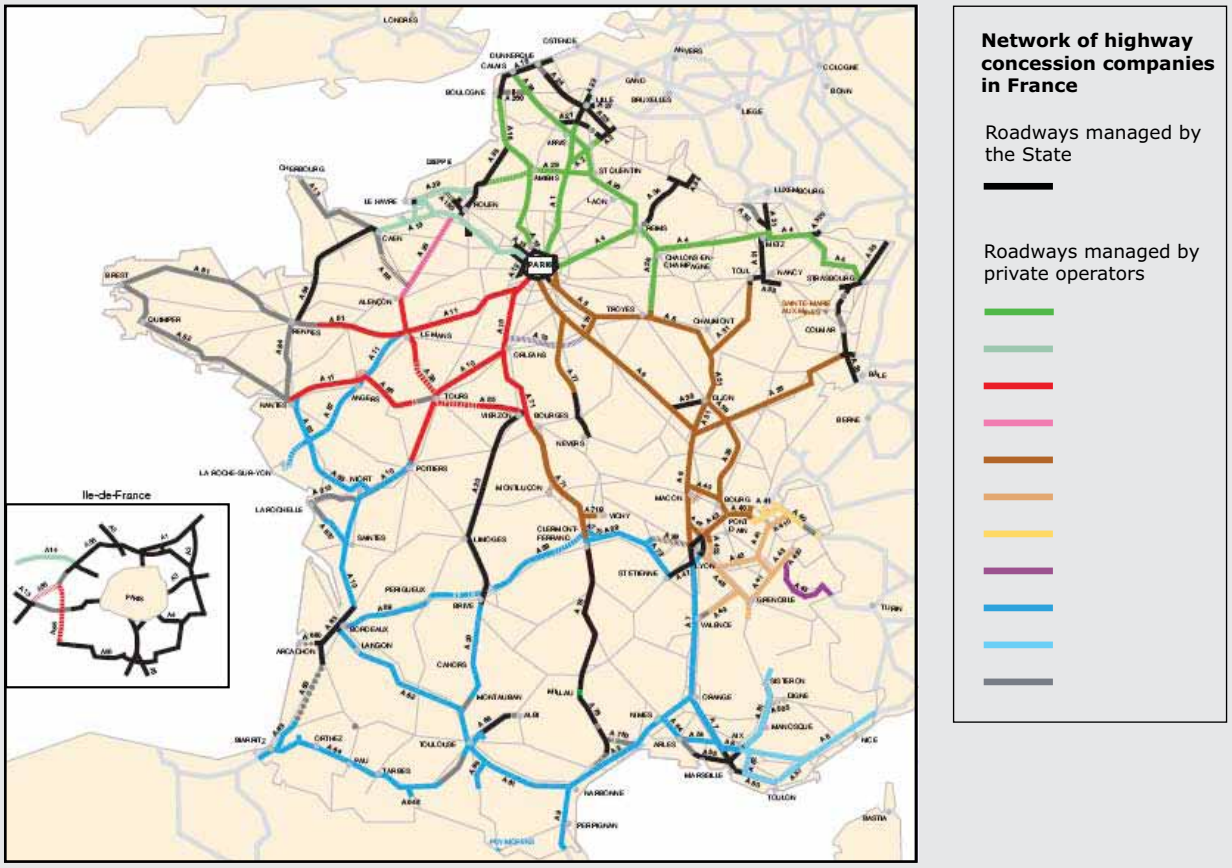
Box 4.5 Concession granting in the transport sector: considering regional climate impacts and avoiding moral hazards on adaptation actions

The likely impacts of climate change on the controlled-access highway system in France will vary by region, and thus by concessionaire (Map 4.1). Companies operating in different localities will therefore need to take different types of adaptation response, often at increased costs, which may not be tolerated by all shareholders. A given company would be at a comparative disadvantage to its competitors when the level of investment required for the adaptation of its infrastructure is greater than that of other companies operating in geographic areas with potentially lower climate-related costs. Moreover, it is expected that revenues generated by the toll road system may be reduced in the coming years due to changes in user modal distribution (transfer to rail and air). Further analysis is therefore needed to understand how these variations and needs for adaptive planning could be included in short- and long-term contracts when paired with decreasing operating budgets (Cochran, 2009).

When considering adaptation measures, it is therefore necessary to consider the extent to which they take into account the current and projected regional climate change impacts, their impacts on the competition between private actors, and their consequences in terms of risks of moral hazard.

In the case of the French highways, concession contracts could be structured in such a way as to factor-in the climate change dimension to incentivise private operators to take certain adaptation measures.

Map 4.1 Network of highway concession companies in France



Source: Cochran, 2009 and MEEDDAT, 2005.

consideration of those risks associated with a 4 °C increase.

Adaptation to address changes in climate has for the most part been envisioned as an incremental process focusing on short-term solutions, with an emphasis on low-regret measures (e.g. increasing resilience and avoiding disruptions of particular systems). However, in some cases, the risks may be so great that incremental adaptation strategies may be insufficient (Kates et al., 2012), or the costs and implications of incremental strategies may be unacceptable. In these cases, transformational adaptation strategies will be required. In many of these cases, due to the complexity of the transformation required, transformational adaptation strategies are such that they will need to be divided up into smaller transitional adaptation measures, which can be implemented over an appropriate and manageable timeframe.

Examples of transformational adaptation in practice are currently limited but do exist. Measures that are truly new to a particular region or resource system include:

- Introducing new crops or cropping systems to a particular region (Rickards and Howden, 2012). This can be seen in the trend for some larger wine companies to purchase land in areas where the climate is projected to become more suitable for wine production in the near to medium-term;
- Replanting forests with species that are likely to be more suitable under the projected climate throughout that species lifecycle;
- Use of waste water and brackish water to enhance water supply;
- Intentional assisted colonisation of wildlife species to maintain and enhance biodiversity; or
- Introduction of behavioural changes to reduce water demand.

Examples of transformational adaptation measures that transform places or shift activities to new locations include:

- Retreat and relocation of communities and infrastructure due to unacceptable risks of flooding or coastal erosion;
- Relocating farming and industry to areas where water availability is more consistent with agricultural or industrial requirements, and replacing them with less water-intensive activities;
- Fundamental changes in governance structures and priorities that change planning practices (e.g. in forestry and agriculture).

Transformational adaptation measures often have 'knock-on' effects in different areas. Sometimes it may be necessary to implement a measure at one scale (for example a specific location) in order to reduce the overall costs of implementing a measure or achieving a certain outcome at a larger scale (e.g. nationally). However more analytical work is needed to understand these relationships.

'Anticipatory' transformational adaptation (adaptation that occurs before climate or other impacts occur) may be difficult to implement. This is because of uncertainties about climate change risks and adaptation benefits; the high financial and social costs of the proposed transformational

Box 4.6 Defining transformational and incremental adaptation

Transformational adaptation measures are behavioural and technological actions that result in fundamental (but not necessarily irreversible) changes in the biophysical, social or economic components of a system. It includes planned and responsive measures that are truly new to a particular region or resource system, and those that shift certain activities to new locations (for example moving agriculture to different areas). Transformational adaptation can result from both discrete changes/actions or a series of rapid incremental changes in a particular direction. Transformational adaptation may be viewed positively in terms of gains and negatively in terms of losses or limits of adaptation having been reached.

Incremental adaptation is less radical. It is the extension of actions that are normally taken to reduce losses or enhance benefits that come with climate variability and extreme events. These can include increasing existing flood defences; modification of extreme weather warning systems; augmenting water supply by increasing the size or number of reservoirs or decreasing demand; and ecosystem and forest management measures. Incremental adaptation measures are those that have been already tried and are familiar within a region or system — doing more of what is already being done to deal with current climate variability and extremes.

actions; and the institutional and behavioural contexts that tend to maintain existing resource systems and policies. Transformational adaptation requires even more planning and institutional adaptive capacity, as it requires an understanding of where, when and how there is a need for action. It also implies a complex change in practices. Key factors for the success of transformational adaptation will be the involvement of stakeholders, together with securing funding, and the monitoring and evaluation of progress. Adaptive management will also be instrumental to the successful implementation of transformational adaptation.

Transformational adaptation has implications for adaptation policies at EU level, particularly in connection with trans-boundary issues. Transformational adaptation requires the coordination of responses at all levels of governance and decision-making to ensure that coherent planning and coherent measures are developed. In addition, EU financial instruments, such as the Cohesion funds, could help to attract other private and public investment. This would alleviate some of the financial challenge of transformational adaptation for regions or cities that might not have the financial capacity to implement such measures on their own.

4.3.5 Drivers of and obstacles to adaptation

It is imperative to understand the factors that can assist in the implementation of adaptation, as well as the factors that can hinder the implementation of adaptation. This understanding can be gained by analysing case studies of adaptation implementation. This will improve our knowledge of how EU action can support capacity building and good practices such as adaptive management.

Climate change affects all regions differently. This makes adaptation a complex task, and the complexity is increased by the fact that climate change affects all levels of decision-making and a variety of sectors and actors. These inter-linkages lead to a number of obstacles that can hinder coherent adaptation policymaking (see also Box 1.2 and Grothmann, 2011; Prutsch et al., 2010).

Obstacles to adaptation

In general, barriers are 'obstacles that can be overcome with concerted effort, creative management, change of thinking, prioritisation, and related shifts in resources, land uses, institutions, etc.' (Moser and Ekstrom, 2010; Jones, 2010). Obstacles to effective climate change adaptation may result from one or more of market failures, regulatory barriers, governance/institutional barriers and behavioural barriers (Productivity Commission 2012). Below we deal with each of these barriers in turn:

- *Market failures* — conditions that prevent markets from achieving the most efficient allocation of resources. For example, a barrier to adaptation could occur where there is insufficient or inadequate information on climate change impacts for consumers, organisations or the private sector to make well-informed adaptation decisions. Similarly, moral hazard can lead actors to take risks that they know other actors will have to pay for, for example people building homes in areas prone to flooding, confident that the government will build flood protection measures as part of its adaptation strategy. It is imperative that governance structures are put in place to ensure that adaptation policy is not affected by these risks. Finally, public authorities have a role in incentivising early action by front runners and novel technologies, and making sure that public action does not deter private investments (i.e. the 'crowding out' effect);

- *Regulatory barriers* — regulations that inhibit effective adaptation. For example, the building regulation system and the planning regulation system may not be integrated, and as a result neither system might address a particular environmental hazard (such as riverine flooding). This leads to gaps in the regulatory framework;

- *Governance and institutional barriers* — governance arrangements that are not consistent with best practice. This can impede coordination between governments and agencies, reduce accountability, or lead to authorities being allocated responsibilities for which they do not have sufficient capacity to carry out effectively. For example, the current legal liability of regional and local governments is uncertain when making land-use planning decisions relating to land that is subject to future climate change risks. In some cases, councils may defer decisions as they are uncertain about the legal implications of their decisions;

- *Behavioural barriers* — the ways people process information and make decisions, which could act as a barrier to effective adaptation.

For example, individuals may have trouble weighing up costs and benefits that occur over long time-frames. As a result, some people may respond to the long time-frames and uncertain impacts of climate change by procrastinating and deferring adaptation decisions that would be in their own best interest.

The EEA (2009) identified a set of obstacles to adaptation on the basis of case studies and a literature review. These obstacles were grouped under three main headings:

- *Limited scientific knowledge and uncertainty* about future climate change's local impacts on water availability, quality and demand. This is clearly a key barrier to political commitment to anticipatory and forward-looking adaptation measures. This is partly due to the great uncertainties in downscaling climate models and scenarios;

- *The lack of long-term planning strategies, coordination and use of management tools* that consider climate change at regional, river basin and cross-sectoral levels. This hinders sustainable development of resources (e.g. water), and is a key barrier to effective adaptation. Communities or regions connected in a network are generally better than isolated, un-networked communities at coping with local problems (e.g. shortages in water supply) and help avoid uncoordinated actions or maladaptation;

- *Climate change is seldom considered explicitly* in resource management plans. This means that resources-related adaptation measures responding specifically to current and future climate change impacts are still largely absent. This is partly due to the limited knowledge base on climate change impacts at the local and regional levels. A series of EU initiatives on mainstreaming adaptation in sectoral policies (e.g. the Water Framework Directive and River Basin Management Plans) goes some of the way to addressing this shortcoming.

Clar et al. (2012) present an approach that uses the stages of the policy cycle as an organising framework to summarise the key obstacles in adaptation policymaking as found in the scientific literature. At least 6 of the 16 key obstacles they identify can be regarded as cross-cutting, not only in the sense that they are relevant for all stages of the policy cycle, but also in the sense that they are closely related with each other. These cross-cutting examples are:

- lack of political commitment;
- responsibilities are inadequate or unclear;
- inadequate cooperation;
- not enough human and financial resources;
- lack of scientific evidence or certainty of climate change risks (i.e. uncertainty);
- insufficient knowledge-sharing and networking.

The remaining 10 obstacles play a prominent role in one of the four policy cycle stages:

1. Agenda setting
   - too little or no awareness among; policymakers (communication challenge),
   - priorities are disputed.

2. Policy formulation and decision-making
   - lack of expertise among policymakers,
   - conflicting values and interests;
   - available options are unsatisfactory for decision-makers and policymakers.

3. Policy implementation
   - adaptation policy is politically/ administratively infeasible;
   - no adequate technological (grey), green or soft measures available;
   - legal issues.

4. Policy monitoring and evaluation
   - complexity of policy impacts and outcomes;
   - lack of experience with monitoring and evaluation practices in the context of adaptation.

Drivers of adaptation

The EEA (2009) also identified, on the basis of case studies and a literature review, a set of success factors for adaptation. Political support is a key catalyst for initiating, driving and coordinating adaptation, providing a strategic framework for effective action. Most adaptation policies that have been implemented have generally been responses to extreme events or natural hazards that created public pressure for action by public authorities.

But political support is only one of the drivers of successful adaptation policy. Adaptation measures rely on a broad variety of factors for their success, many of which are the result of institutional and governance structures:

- Measures are generally more accepted and successful when they promote (or at least do not conflict with) other goals, including economic goals. Effective adaptation processes therefore depend a great deal on the people involved and their motivations, as well as governance factors such as stakeholder participation processes or cooperative structures;

- A sound legal framework is a crucial complement to political support. It can provide a clear mandate for establishing cooperation at the cross-sectoral, inter-regional, or water basin scale. This facilitates the sharing of resources and the coordination of stakeholders;

- An increasing number of initiatives consider soft actions, such as behavioural adaptation and ensuring the full participation and empowerment of stakeholders. These play an important role in complementing grey and green measures by initiating action and supporting the adaptive capacity of stakeholders;

- Introducing market-based economic incentives (e.g. pricing of resources such as water) and financial support (e.g. subsidies) is also helpful in encouraging proactive and innovative adaptation measures. Such incentives also help to encourage private sector participation;

- It is vitally important to raise stakeholder awareness about the need for anticipatory adaptation actions. This is especially true in sectors with long planning horizons (i.e. where long-term investments are needed) such as forestry and power generation. Long-term adaptation planning occurs mainly in those sectors, while other sectors plan and act on the basis of shorter timeframes;

- The consideration of other social factors, in particular pre-existing local practices and social networks, is also key. These social factors include: traditional irrigation systems; unwritten rules; the current distribution of responsibilities; and existing communication networks. Although they do not need to be formally institutionalised, these practices and networks can all decrease conflicts between stakeholders and facilitate adequate adaptation responses.

The EEA (2009) also highlights that the successful transfer of lessons learned to other regions is far from straightforward.

In addition to the success factors listed above, other studies (e.g. Biesbroek et al., 2010; Dumollard and Leseur, 2011; Greiving et al., 2011; BMVBS, 2010) stress the importance of additional factors. These include: good cooperationbetween ministries; policy coherence; adequate research-based knowledge; the ability to enhance the capacity for both mitigation and adaptation simultaneously; and consideration of potential synergies and conflicts between adaptation and other change processes such as demographic and economic changes.

4.3.6 Costs and benefits of adaptation

This section provides an overview of current knowledge in estimating the costs and benefits of adaptation ([60]). More analytical work is needed in this area before these estimates can fully inform adaptation decisions. This section is complemented by further detailed sectoral estimates and by a discussion of methodology, both of which are available in Annex 4.

The costs and benefits of adaptation play an important part in the assessment of any adaptation measure. This information is potentially relevant at a number of different 'aggregation' levels. These aggregation levels include:

- The regional or local level, where information on the costs and benefits of adaptation can allow for the design and prioritisation of adaptation policies, programmes and projects. At this level, information on costs and benefits can also be used in the appraisal of these projects.

- The national level, where information on costs and benefits is relevant for national adaptation strategies, plans and financing needs, and for prioritisation decisions on adaptation policies and programmes. This allows for efficient, effective and equitable response

([60]) This section was compiled by Paul Watkiss. The research for this input received funding from the European Community's Seventh Framework Programme, as part of the ClimateCost (http://www.climatecost.cc) Mediation Project (http://www.mediation-project.eu) and the IMPACT2C (http://www.hzg.de/mw/impact2c). projects.

strategies, including national plans. A number of national-level assessments have considered adaptation costs and benefits. These include Sweden (SCCV, 2007) and the Routeplanner assessment in the Netherlands (van Ierland et al., 2006; de Bruin et al., 2009b). Detailed assessment work that considers the costs and benefits of adaptation is also underway in many Member States, such as in the United Kingdom with its Economics of Climate Resilience project, and in Germany under the Kompass project ([61]).

- The European level, where information on the costs and benefits of adaptation can raise awareness on the issue and scale of adaptation. Information at this level can also provide input for the implementation of the EU Strategy on Adaptation to Climate Change, the Multiannual Financial Framework 2014–2020, and other financing sources for climate-proofing EU policies. As an increasing number of studies assess adaptation responses, one challenge is to also include EU-wide assessments of the costs and benefits of these responses.

- The global level, where information on costs and benefits has been used to raise awareness. The discussion on how adaptation around the world will be financed — especially in most vulnerable and developing countries — has also made use of this information. These discussions typically use global integrated assessment models and global investment and financial flow analysis (e.g. UNFCCC, 2007; World Bank, 2010; de Bruin et al., 2009a; Aaheim et al., 2010).

Estimates of costs and benefits ([62]) at European, Member State, and local level are emerging (e.g. those made in reviews such as EEA, 2007; OECD, 2008; Parry et al., 2009; UNFCCC, 2009; CEPS/ZEW, 2010; Watkiss, 2011; Agrawala et al., 2011). However, the studies are preliminary and not yet refined enough for use in all decision-making circumstances as they are often not comprehensive (e.g. only a sub-set of sectors are covered) and have clear methodological limitations. This is due to several methodological issues with adaptation economics that have not yet been resolved. These issues are mainly due to the complexity of estimating costs and benefits for measures that depend on a large number of variables. These variables include: spatial scale, specific geographic conditions, social and economic context, and the estimated extent of climate change.

Several different methods and models are currently being used in order to improve estimates of the costs of adaptation (See Sections A4.2 and A4.3 of Annex 4 for further details about methods for assessing adaptation costs and benefits). At the European scale, a number of studies have recently provided cross-sectoral cost assessments as part of consistent sectoral assessments, notably in the EU FP7-funded ClimateCost Project (Watkiss, 2011). A large number of studies and estimates are also emerging at Member State level, though these are not reported systematically in this report. We must bear in mind that these studies — whether focusing on the European level or the national level — cannot be directly compared with one another due to the variations in methodology used in each study.

As part of the EEA's 2010 State of the Environment and Outlook Report, an indicative analysis was made of the availability of cost and benefit information by sector (Table 3.3 in EEA, 2010b). This table has been updated below (Table 4.3). Section A4.1 of Annex 4 provides detailed sectoral estimates.

Interestingly, in recent years, computable general equilibrium (CGE) models have been used to look at the wider economic costs of adaptation. These have been used in a number of ways (e.g. to assess the wider economic costs of adaptation for the coastal sector). Carraro and Sgobbi (2008) moved to the national level, and assessed the economic value of the impacts of climate change for economic sectors and regions. They aggregated this value to provide a macroeconomic estimate (GDP) using a CGE model. Carraro and Sgobbi included in their model 'autonomous' adaptation induced by changes in relative prices and in stocks of natural and economic resources, as well as international trade effects (changes in prices inducing changes in production and demand).

Overall there is a need to improve our knowledge of the costs and benefits of adaptation. This will help provide basic cost/benefit ratios and identify obvious low-regret options (e.g. on water efficiency). In addition to information on the costs and benefits of adaptation it would be useful to

([61]) See report 'Costs and benefits of climate change adaptation measures' (September 2012) available at http://www.umweltdaten.de/publikationen/fpdf-l/4298.pdf.
([62]) Benefits are estimated as 'avoided damage costs'.

Table 4.3 Coverage of studies for European adaptation costs and benefits

Sector	Coverage	Cost estimates	Benefit estimates
Coastal zones	Very high coverage (infrastructure/erosion) for Europe, regions, Member States as well as cities/local ([1])	√√√	√√√
Infrastructure including floods	Medium. Adaptation cost estimates at EU level and for several countries for flooding, but lower coverage of other infrastructure risks ([2])	√√	√√
Agriculture	High coverage of farm-level adaptation benefits, and now Member State and European benefits. Medium coverage for costs and planned adaptation ([3])	√	√√
Energy	Medium — low. Some studies on cooling/heating demand (autonomous adaptation *) for Europe and Member States. Some national studies on planned adaptation. Some studies on energy supply ([4])	√√	√√
Health	Medium. Some studies of adaptation costs for heat alert and food-borne disease, but lower coverage of other health risks ([5])	√√	√
Water	Medium — low. Some emerging estimates of costs of measures and national studies. Some national, river basin or sub-national studies on water supply ([6])	√√	√
Transport	Low — medium. Some national and individual sub-sector analysis ([7])	√	√
Tourism	Low — medium. studies of winter tourism (Alps) and some studies of autonomous adaptation from changing summer tourism flow *([8])	√	√
Forestry and fisheries	Low — limited number of quantitative studies.	√	√
Biodiversity/ecosystem service	Low — limited number of studies on restoration costs.		
Business and industry	Very low — no quantitative studies found.		
Adaptive capacity	Low — selected studies only and only qualitative descriptions of benefits.		
Indirect and cross-sectoral	Low — some emerging estimates related to floods.		
Macro-economic effects	Low. Some emerging studies, although sectoral coverage limited (reflecting evidence in sectors above) ([9])	√	√
International effects (into the EU)	Very low — no quantitative studies found.		

Note: See main text for discussion and caveats.

* Note can be considered an impact or an adaptation.

Examples of citations for rankings presented in the table:
([1]) Brown et al., 2011; Evans et al., 2004 and 2008; EA, 2009a and 2011.
([2]) Feyen et al., 2011; Evans et al., 2004; EA, 2009a; EEA, 2007; Broekx et al., 2011; Lamothe et al., 2005; SCCV, 2007.
([3]) Watkiss, P., 2011.
([4]) Mima et al., 2011; van Ierland et al., 2006; Arup, 2008; Jochem and Schade, 2009.
([5]) WHO, 2009; Kovats, 2009; Kovats et al., 2011.
([6]) Bosello et al., 2009; Flörke et al., 2012.
([7]) SCCV, 2007.
([8]) OECD 2007.
([9]) Carraro and Sgobbi, 2008; Bosello and Roson, 2009.

Key:
√ Low coverage with a small number of selected case studies or sectoral studies.
√ √ Some coverage, with a selection of national or sectoral studies.
√ √ √ More comprehensive geographical coverage, with quantified cost (or benefit) estimates at aggregate levels.

Source: Updated from EEA, 2010b and Watkiss and Hunt, 2010.

have an indication about financing sources for the different types of adaptation, i.e. the share of public, private and mixed funding in grey, green and soft actions. This would give a clearer picture of the respective distribution of financial responsibilities.

4.4 An adaptation road-map for the EEA

This report has addressed adaptation policy in Europe through presenting examples of adaptation actions, reviewing the policy context, and setting out some of the issues that will shape the future of adaptation decision-making.

Adaptation is an area of work of increasing importance at the European Environment Agency (EEA). The policy response needs to be further supported, strengthened and coordinated at EU level and across the member countries. The EEA's mandate is to support decision-making at EU and national levels by providing timely, targeted, relevant, reliable, and up-to-date information and assessments to policy agents and the public.

In future, the EEA will continue to support adaptation decision-making across Europe and the implementation of the EU Strategy on Adaptation to Climate Change. It will focus its work on three main areas:

1. **Providing up-to-date information and data about the state of play of adaptation in Europe at the European Climate Adaptation Platform (Climate-ADAPT)**.

   The provision of up-to-date information and data about adaptation in Europe is a critical tool for decision-making. Adaptation stakeholders in Europe need EU-wide and country-specific information on adaptation and tools that can support their planning and implementation activities. The Climate-ADAPT platform, in operation since March 2012, has enhanced the sharing of information and is now the EU's entry point for adaptation information in Europe. Its visibility to stakeholders is high (15 000 visitors per month on average).

   It is critical that the EEA, with the support of the European Commission and the research community, ensures that this information is updated and shared widely, and continues to meet the demand from the EEA's stakeholders. The sections of Climate-ADAPT most relevant to these stakeholders include: the country pages, which describe adaptation activities initiated at national and sub-national levels; the Adaptation Support Tool, which guides stakeholders through a series of steps and questions critical to adaptation planning; the overview of EU sectoral policies and related initiatives to mainstream adaptation; the Case Study Search Tool, which allows visitors to access information on adaptation measures that have already been implemented across Europe; the scenarios and impacts indicators; and the Map Viewer, which gives access to EU-wide spatial information about climate variables and vulnerabilities.

2. **Assessing the latest information and providing policymakers with analytical work that helps them plan and implement adaptation actions.**

   Another critical activity for the EEA is to assess the latest information and provide policymakers with analytical work that helps them plan and implement adaptation. As there is an increasing amount of information available on adaptation, it is important that this is analysed to report on progress made on adaptation in Europe, and presented in a way that is tailored for policymaking.

   The EEA will provide on a regular basis up-to-date and in-depth EU-wide analysis. This analysis will give a state-of-play overview of adaptation in Europe, and review good practice. It will also review the use of funding mechanisms for adaptation available under the EU's 2014–2020 Multi-annual Financial Framework (e.g. cohesion funds, agriculture and infrastructure funds, LIFE+ instruments, and Horizon 2020). The EEA will add value by providing assessments at regular intervals, supporting policymaking with a stable (yet improving) analytical methodology that uses the latest available science and indicators about climate change impacts and vulnerability in Europe.

3. **Strengthening the knowledge base in some areas that suffer from a deficit of information and assessments such as: the costs and benefits of adaptation; reviews of actions implemented by businesses and the private sector; indicators for monitoring and evaluating adaptation; and the resilience of European territories in relation to green infrastructure and spatial planning.**

   It is vitally important to strengthen the knowledge base in areas that suffer from a deficit

of information and assessments. This helps to ensure that policymaking is continuously informed with the latest information, enhancing the coherence of adaptation action. Costs and benefits of adaptation are a key element in assessing adaptation actions and need additional attention.

Another issue that requires additional attention is the review of adaptation actions planned and implemented by businesses (e.g. utilities) and the private sector (e.g. insurance and banking sectors). Utilities are often large companies with substantial financial resources that can be used to effectively mainstream adaptation. Moreover, the way they plan and provide their services (e.g. energy, water, transport and ICT) can substantially impact the resilience of European society.

A third issue that needs attention is the need for more work on indicators for monitoring, measuring progress, and evaluating adaptation. This will help to implement adaptive management that builds on previous experiences, and will support flexibility in decision planning.

Finally, it is important to make further progress on approaching adaptation from a spatial planning perspective. This will mean giving greater consideration to nature and green infrastructure that strengthens the resilience of European territories in the short and long term.

Annex 1 Overview description of examples and additional information sources

Table A1.1 below provides an overview description of examples included in Chapter 2 of this report. It also gives a series of additional information and links.

Table A1.1 Examples included in Chapter 2 and additional information sources

	Main types of adaptation actions			Key elements of adaptation actions in Europe							
	Grey	Green	Soft	Strengthening the knowledge base	Mainstreaming adaptation	Territorial cohesion	Ecosystem-based approaches	Multi-level governance	Stakeholder involvement	Adaptation pathways	Insurance and economic instruments
Examples presented in this report											
Technological, monitoring, and survey actions (France) (Section 2.2.1)	√				√				√		
Manage flood risks in estuary (Belgium) (Section 2.2.2)	√					√	√		√		
Desalination for water supply (Spain) (Section 2.2.3)	√			√	√				√		
Small-holder farmers (Sweden) (Section 2.3.1)		√	√	√	√		√		√		
Green infrastructure (The Netherlands) (Section 2.3.2)		√	√		√	√	√	√	√		
Adaptation in the wine sector (Spain) (Section 2.3.3)		√	√	√	√	√	√		√		
Restoration of peatlands (Ireland) (Section 2.3.4)		√	√	√		√	√				
Sustainable forest management (Pan-European) (Section 2.3.5)		√	√	√			√	√	√		
Restoring the lower Danube wetlands (Danube river basin) (Section 2.3.6)		√	√		√	√	√	√	√		
Regional early warning systems (Italy) (Section 2.4.1)	√		√	√	√			√	√		
European early warning systems (Pan-European) (Section 2.4.2)	√		√		√				√		

Table A1.1 Examples included in Chapter 2 and additional information sources (cont.)

	Main types of adaptation actions			Key elements of adaptation actions in Europe							
	Grey	Green	Soft	Strengthening the knowledge base	Mainstreaming adaptation	Territorial cohesion	Ecosystem-based approaches	Multi-level governance	Stakeholder involvement	Adaptation pathways	Insurance and economic instruments
Insurance schemes against natural hazards (Switzerland) (Section 2.4.3)			√	√	√	√					√
Community network in Bratislava (Slovakia) (Section 4.2.2)			√	√	√			√	√		
Cross-departmental collaboration and external stakeholder involvement in Kalamaria (Greece) and in Genoa (Italy) (Section 4.2.2)		√	√	√	√		√	√	√		
Restoring seaside — Integrated coastal adaptation (France) (Section 2.5.1)	√	√	√	√	√	√	√	√	√		
The Thames Barrier (UK) (Section 2.5.2)	√	√	√	√	√			√	√	√	
The Dutch Delta Programme (the Netherlands) (Section 2.5.3)	√	√	√	√	√			√	√	√	
Portfolio of actions in urban areas (Pan-European) (Section 2.5.4)	√	√	√	√	√	√	√	√	√		
Financing adaptation measures (Pan-European) (Section 2.5.5)	√	√	√	√	√	√	√	√	√		
Additional information sources											
ClimWatADAPT (DG ENV, Water) (1)	√	√	√		√	√	√				√
OurCoasts (DG ENV, ICZM) (2)	√	√	√		√	√	√		√		
Adaptation for urban areas — GRABS INTERREG project (3)	√	√	√	√	√		√	√	√		
DG Environment (ecosystem-based approaches; green infrastructure) (4)		√		√	√	√	√		√		
CIRCLE-2 Climate Adaptation InfoBase (5)	√	√	√	√	√		√	√	√		
EEA report — Changing water resources in the Alps (6)	√	√	√	√	√		√	√	√		√
ESPON-Climate (7)	√	√		√		√		√			
DG CLIMA service contract on Climate change adaptation in Cities (Final results mid 2013) (8)	√	√	√	√	√			√	√		
ClimateChange-Adaptation (Denmark, National portal) (9)	√	√	√	√	√		√	√	√		

Table A1.1 Examples included in Chapter 2 and additional information sources (cont.)

	Main types of adaptation actions			Key elements of adaptation actions in Europe							
	Grey	Green	Soft	Strengthening the knowledge base	Mainstreaming adaptation	Territorial cohesion	Ecosystem-based approaches	Multi-level governance	Stakeholder involvement	Adaptation pathways	Insurance and economic instruments
Kompass Tatenbank (Germany, National portal, in German) ([10])	√	√	√	√	√	√	√	√	√		
Cities of the Future (Norway) ([11])	√	√	√	√	√			√	√		
Integrated Management of Natural Hazards (Switzerland) ([12])	√	√	√	√	√			√	√		
EUROCONTROL ([13])	√		√	√	√			√			

Note:

([1]) http://climwatadapt.eu.

([2]) http://ec.europa.eu/ourcoast/index.cfm?menuID=3.

([3]) http://www.grabs-eu.org.

([4]) http://ec.europa.eu/environment/nature/climatechange/pdf/EbA_EBM_CC_FinalReport.pdf; http://ec.europa.eu/environment/enveco/biodiversity/pdf/GI_DICE_FinalReport.pdf.

([5]) http://infobase.circle-era.eu.

([6]) http://www.eea.europa.eu/publications/alps-climate-change-and-adaptation-2009.

([7]) http://www.espon.eu/main/Menu_Projects/Menu_AppliedResearch/climate.html.

([8]) http://eucities-adapt.eu/cms.

([9]) http://www.klimatilpasning.dk/DA-DK/SERVICE/CASES/Sider/Forside.aspx (in Danish); http://www.klimatilpasning.dk/en-US/Service/Cases/Sider/Forside.aspx (in English).

([10]) http://www.tatenbank.anpassung.net/Tatenbank/DE/Home/home_node.html, including results of the annual adaptation contest (http://www.tatenbank.anpassung.net/Tatenbank/DE/3_Wettbewerb/wettbewerb_node.html;jsessionid=E48EAE9E8836A922956E504D05C6C41E.1_cid346).

([11]) http://www.regjeringen.no/en/sub/framtidensbyer/cities-of-the-future-2.html?id=551422.

([12]) http://www.bafu.admin.ch/naturgefahren/01922/index.html?lang=fr.

([13]) http://publish.eurocontrol.int/sites/default/files/content/documents/official-documents/facts-and-figures/statfor/challenges-of-growth-climate-adaptation-march-2010.pdf.

Annex 2 Mapping of EU policy initiatives and related sectors

Table A2.1 below shows a mapping of EU policy initiatives and related sectors. It is an annex to Section 3.1.2 on Mainstreaming.

Table A2.1 Mapping of EU policy initiatives and related sectors

	Water management	Marine and fisheries	Coastal areas	Agriculture	Forestry	Biodiversity	Infrastructure	Finance and insurance	Disaster risk reduction	Health
CURRENT INITIATIVES										
Water management										
Water Framework Directive (WFD)	■			■	■	■				
Floods Directive	■		■			■			■	
Communication on addressing the challenge of water scarcity and drought in the EU, and the forthcoming 2012 Water Scarcity and Droughts policy review	■			■						
2012 'Blueprint to Safeguard Europe's Water'	■									
Marine and fisheries										
EU Integrated Maritime Policy and action plan		■	■							
Marine Strategy Framework Directive (MSFD)		■	■			■				
Maritime Spatial Planning		■	■							
Marine Knowledge 2020		■	■							
Coastal areas										
Integrated Coastal Zone Management (ICZM), the Protocol on Integrated Management of Coastal Areas for the Mediterranean, the 2002 ICZM recommendations, and the OURCOAST initiative			■			■				
Agriculture										
2003 Reform of the Common Agricultural Policy (CAP), the so-called Health Check (2008), and the EC Communication on the CAP towards 2020				■		■				
Forestry										
EU Forestry Strategy and the 2006 EU Forest Action Plan					■					
2010 Green Paper on options for an EU approach to forest protection and information systems					■					
Biodiversity, green infrastructure										
2006 Soil Thematic Strategy, and Draft Proposal for a Soil Framework Directive						■				
Habitats and Birds Directives in the Natura 2000 network						■				
EU Ad Hoc Expert Working Group on Biodiversity and Climate Change (2009), and forthcoming Draft guidelines on dealing with the impact of climate change on the management of Natura 2000 sites						■				
SEBI2010 (Streamlining European 2010 Biodiversity Indicators)	■					■				

Table A2.1 Mapping of EU policy initiatives and related sectors (cont.)

	Water management	Marine and fisheries	Coastal areas	Agriculture	Forestry	Biodiversity	Infrastructure	Finance and insurance	Disaster risk reduction	Health
The Biodiversity Information System for Europe (BISE)						■				
2010 EC Communication on possible future options for a long-term (2050) EU vision on biodiversity policy and mid-term (2020) targets beyond 2010						■				
EU 2020 Biodiversity Strategy (2011), and specifically target 2 on Maintaining and restoring ecosystems and their services	■	■	■	■	■	■	■			
Cohesion, impact assessments, infrastructure and networks										
Regional-Cohesion Policy and related Funds (Cohesion Fund and Structural Funds (European Regional Development Fund (ERDF), European Social Fund (ESF))							■	■	■	
Operational Programmes (OP) and National Strategic Reference Frameworks (NSRF)							■	■		
EU Solidarity Fund							■	■	■	
Thematic Strategy on the Urban Environment							■			■
The 10 Eurocodes for buildings, other civil engineering works and construction products (series of European Standards)							■		■	
TEN-T (Trans-European Transport Networks, EU Transport policy) and TEN-E (Trans-European Energy Networks, EU Energy policy)			■				■	■	■	
Financial										
The Financial Services Action Plan, in view of the creation of a single insurance market								■	■	
The 2009 Solvency II Directive for insurance companies								■	■	
Disaster risk reduction										
2009 EC Communication on disaster risk prevention									■	
2010 EC working paper on 'Risk assessment and mapping guidelines for disaster management'									■	
2010 EC Communication 'Towards a stronger European disaster response: the role of civil protection and humanitarian assistance'									■	
Health										
The EU health strategy (European Commission's Public Health Programme; and its Executive agency for health and consumers; and the European Centre for Disease Prevention and Control (ECDC))										■
The Commitment to Act and the European Regional Framework for Action (World Health Organisation's Regional Office for Europe, 5th Ministerial conference on Environment and Health, March 2010)										■
2011 European Commission proposal for a Decision on serious cross-border threats to health										■
FORTHCOMING ACTIONS										
Common Fisheries Policy reform		■								
Reviewed ICZM recommendations			■							
Commission legal proposals (October 2011) to reform the CAP after 2013: 'Greening' of instruments, and schemes that support production through market and income policy (Pillar 1)				■						
Commission legal proposals (October 2011) to reform the CAP after 2013: Common Agricultural Policy's (CAP) Rural Development instrument (supporting the sustainability of rural areas from a territorial perspective through rural development (Pillar 2), taking into account regional climate change impacts and vulnerabilities)	■			■	■	■				
New EU Forest Strategy					■					

Table A2.1 Mapping of EU policy initiatives and related sectors (cont.)

	Water management	Marine and fisheries	Coastal areas	Agriculture	Forestry	Biodiversity	Infrastructure	Finance and insurance	Disaster risk reduction	Health
Draft Guidelines on Climate Change and Natura 2000 — Dealing with the impact of climate change on the management of the Natura 2000 Network						■				
EC Green Paper on Green Infrastructure — Working with Nature	■	■	■	■	■	■	■		■	■
Practical Guidance for Integrating Climate Change and Biodiversity into EIA (Environmental Impact Assessment) and SEA (Strategic Environmental Assessment) Directives' procedures	■	■	■	■	■	■	■		■	■
EU guidelines on minimum standards for disaster prevention									■	
European Commission proposals for both a new EU Plant Health legislation and a new EU Animal Health legal framework revising the EU Animal Health Strategy 2007–2013				■	■	■			■	■

Note: Details are available on the European Climate Adaptation Platform (Climate-ADAPT) at http://climate-adapt.eea.europa.eu/web/guest/eu-sector-policy/general.

Annex 3 Guidance for adaptation

This annex, which is an extract from Prutsch et al. (2010), briefly reviews the topic of guidance for adaptation and is an annex to Section 4.3.1 on Monitoring and Evaluation.

For most countries in Europe, and also at the EU level, widely acknowledged guiding principles for all levels of decision making are still lacking. However, it should be noted that some of the existing national adaptation plans (e.g. Germany) and regional/local plans (e.g. city of London) include principles of good practice in adaptation. In addition, the United Kingdom, as a frontrunner in adaptation, has published Defra's Climate Change Plan 2010. This plan includes the following key principles, which central government and organisations in the wider public and private sectors have to take into account (HM Government, 2010):

- *Any adaptation needs to be sustainable.* This means that our responses should not add to climate change, or limit the ability of other parts of the natural environment, society or business to carry out adaptation elsewhere. Our responses must avoid any detrimental impacts on other parts of society, the economy or the natural environment.

- *Actions should be flexible.* Although there is still uncertainty over the future climate, we should consider options now and make decisions that maximise future flexibility — in many cases it is failure to take decisions that locks us into inflexible pathways.

- *Action needs to be evidence-based* — making full use of the latest research, data and practical experience so that decision-making is well-supported and informed.

- *Our response to climate impacts should be prioritised* — for example, by focusing more attention on policies, programmes and activities that are most affected by the weather and climate. Other priorities include actions that have long-term implications or long lifetimes; actions where significant investment is involved or high values are at stake; actions where support for critical national infrastructure is involved; or win-win and low-regret solutions.

- *Adaptation measures need to be effective* (reducing the risks from climate change without introducing perverse effects), *efficient* (the long-term benefits of adaptation actions should outweigh the costs), and *equitable* (the effects and costs of the activity on different groups should be taken into account).

These general aspects from the Defra's Climate Change Plan 2010 can be taken as an overall framework in which any good and coherent adaptation should take place. Given the variety of definitions and approaches for good or coherent adaptation, general support is needed on how adaptation action can be put into practice.

The set of generic guiding principles for good adaptation (Figure A3.1) is intended to give direction on how the adaptation process should be carried out to be successful, both for planning and for effectively implementing adaptation. It aims to support adaptation processes for a wide range of situations and actors (e.g. public authorities, businesses, NGOs) by offering a synthesis of key aspects to better deal with the complexity that is inherent when dealing with adaptation.

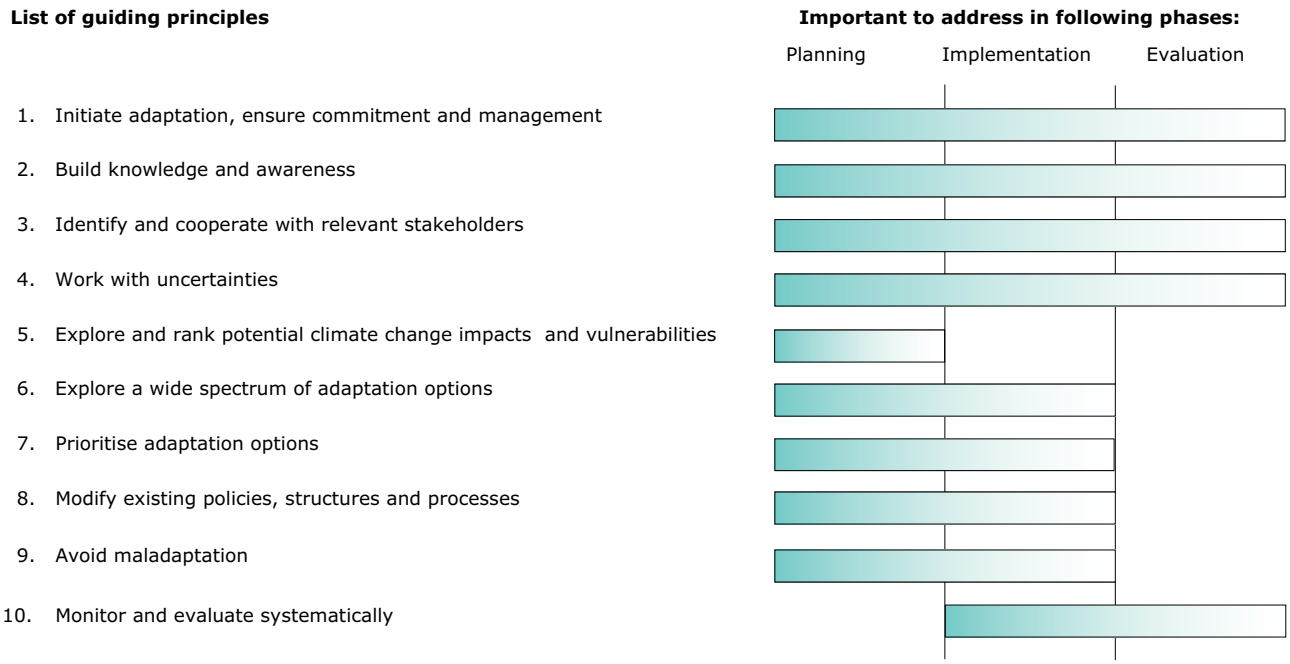
The guiding principles were compiled after a comprehensive literature review, and represent the experience of experts across Europe. 100 different sources of literature on designing, implementing and evaluating adaptation were reviewed to develop this set of overarching adaptation principles. A first draft of the guiding principles was evaluated in a survey by 252 experts and scientists with practical experience and/or planning responsibility in the field of adaptation. They were revised in line with recommendations.

The list of guiding principles gives an indication of key actions in relation to policy-cycle phases. As such, it provides a useful schematic input, which will naturally continue to be developed and interpreted by stakeholders. For example, Figure A3.1 suggests that monitoring relates

primarily to implementation and evaluation although it is certainly important to also consider it during the planning phase. Figure A3.1 also suggests exploring climate change impacts and vulnerabilities primarily for planning purposes, although learning about these effects is certainly a process that is relevant to all policy-cycle phases.

Guidance for adaptation addresses uncertainty and how to deal with it, but only to a limited extent. Since uncertainty is a core challenge of adaptation, this dimension constitutes an area of work that will need to be strengthened in future, building upon recent work, such as Ranger et al. (2010) and Reeder and Ranger (2011).

Figure A3.1 List of guiding principles in relation to key policy-cycle phases



Source: Prutsch et al., 2010.

Annex 4 Sectoral estimates of costs and benefits of adaptation, and methodological aspects

This annex complements Section 4.3.6 by providing detailed sectoral estimates and further methodological consideration.

A4.1 Sectoral estimates

Coastal zones

The most extensively covered sector relates to coastal zones, with coverage at European, national and local scale ([63]). At the EU level, the DIVA model (Vafeidis et al. 2008; Hinkel and Klein, 2009) has been extensively used to derive adaptation costs and benefits. Brown et al. (2011) provide the most recent application (updating previous values from Bosello et al. (2012) in the PESETA project and from Hinkel et al. (2010)). They report that grey adaptation (dyke building; beach nourishment) as well as soft adaptation greatly reduces the overall cost of coastal zone damage costs (estimated by the model at EUR 11 bn/year for the mid estimate of temperature-sea level response by the 2050s (2040–2070) for both the A1B and E1 scenarios (noting that the benefits of mitigation become apparent in the 2080s). The cost of adaptation was estimated at around EUR 1 bn per year (E1) to EUR 1.5 bn per year (A1B) for the 2050s (EU, 2005 prices, undiscounted), and reduced damage costs down to low residual damages, with a benefit-to-cost ratio of 6:1 (A1B(I) mid scenario). Over the long term, climate mitigation also reduces the rate of sea-level rise, and therefore the annual adaptation costs. The adaptation benefit-to-cost ratios were found to increase throughout the 21st century with higher rises in sea level. These estimates of costs and benefits vary with the objectives and the level of protection assumed, as well as with the range of projected impacts across future scenarios and responses. It is also highlighted that hard defences need on-going maintenance to operate efficiently and to keep risks at a low or acceptable level. As the stock of dykes grows throughout the 21st century, maintenance costs will increase, and the annual costs of maintenance could approach or exceed the annual costs of new build or upgrade costs cited above. Importantly, these costs — and the options considered in the model — do not address coastal ecosystem losses. Thus, while adaptation seems an extremely effective response, there is a need to recognise and work with uncertainty — as part of integrated and sustainable policies within integrated coastal-zone management — and this requires an iterative and flexible approach.

Detailed studies on the costs and benefits of adaptation to coastal zones also exist in a number of Member States, notably in the Netherlands (Delta Commissie, 2008) and in the United Kingdom (Evans et al., 2004; 2008; EA, 2009a and 2009b). Finally, there is a set of emerging studies on local responses (e.g. Linham and Nicholls 2012), both in terms of shorelines and in terms of major capital expenditure on city protection. The latter includes some notable studies that adopt cost-benefit assessments within a framework of iterative adaptive management, such as in the Thames Estuary 2100 (TE2100) project (EA, 2009b and 2011; for further details see Section 2.5.2). These also highlight that the capital costs of new protection could be large: a new barrier (the end-of-century option for London) has estimated capital costs of between EUR 8 bn and EUR 10 bn.

River floods

There are also European-wide studies that analyse river flood damage costs, and provide indicative adaptation costs and benefits at the European scale (Feyen et al., 2011 as part of the ClimateCost study). These assessed the costs and benefits of maintaining 1-in-100-year levels of flood protection across Europe in future time periods, set against the increases from climate change under the A1B scenario. The economic benefits of maintaining these minimum protection levels (i.e. the reduction in damage costs or the benefits of adaptation) were estimated at EUR 8 bn/year by the 2020s, EUR 19 bn/year by the 2050s, and EUR 50 bn/year by the 2080s (A1B scenario, mean ensemble, EU-27, climate and socio-economic change current values,

([63]) Estimates are reported for grey and soft adaptation measures as green options were not included in the studies.

undiscounted), although a wide range was found across the multi-model ensemble considered, and there remain large residual damages, which might indicate that a higher level of protection should be considered. From a review of existing literature on the potential costs and benefits of adaptation in Europe at the member-state level (see below), encompassing a wide portfolio of measures, an average benefit-to-cost ratio across the European studies of 4 to 1 was found (though with many individual schemes have much higher ratios). Applying these ratios, the expected annual costs of adaptation were estimated at EUR 1.7 bn/year by the 2020s (2011–2040), EUR 3.4 bn/year by the 2050s (2041–2070), and EUR 7.9 bn/year by the 2080s (2071–2100) (EU 27A1B scenario, mean ensemble, current prices, undiscounted — noting benefit/cost ratios will change significantly when discounted to present values for later time periods). It should be stressed that the benefits and costs vary with the future climate and socio-economic scenario, with the objectives, and with the framework (e.g. risk protection levels). It should also be noted that there is a significant range around these values, which becomes even larger when moving down to Member State level, because of site-specific characteristics. These factors are important as they highlight the need to recognise and work with uncertainty — and adopt an iterative and flexible approach. Nonetheless, the study shows adaptation could be extremely effective.

Similarly, there are a set of national studies at Member State Level, which investigate the costs and benefits of adaptation, for example in the United Kingdom, the Netherlands, Germany, France, Slovakia, and Belgium (e.g. Evans et al., 2004; EA, 2009a; EEA, 2007; Broekx et al., 2011; Lamothe et al., 2005). These include the costs of protection measures, but also include the costs of spatial options (such as 'Room for the River'). There has been less analysis of intra-urban flooding, though some of the Member State-level studies above (notably for the United Kingdom and Germany) include adaptation costs, and this is also becoming an area of interest for assessment at the city level. There has also been work on European-wide assessments of adaptation options for drought and water demand deficits, notably as part of the ClimWatAdapt project (Flörke, et al., 2012, http://www.climwatadapt.eu), which considered the potential cost-effectiveness (economic efficiency) of various options for the water sector. Estimates at member or regional state level indicate that technical (water storage) options could involve high potential costs to address water supply gaps. Similarly, Bosello et al. (2009) estimate that adaptation costs for water supply could be EUR 2.7 bn/year by the 2060s in Western Europe.

Energy sector

In the energy sector, there are now estimates of the costs of cooling as part of autonomous adaptation (which can be considered either as a damage cost or a form of adaptation), with estimates at the EU level. Mima et al. (2011) estimated a strong increase in cooling (and electricity) demand in Europe under the A1B scenario due to warming, with the additional cooling costs from climate change alone estimated at around EUR 30 bn/year in the EU-27 by 2050, rising to EUR 109 bn/year by 2100 (current values, undiscounted), with a strong distributional pattern of cooling increases, with a much higher increase occurring in southern Europe. The study also looked at the potential for planned adaptation, and the costs and benefits of possible measures or strategies for energy demand, focusing on low- and very low-energy consumption buildings, which reduce energy requirements. While these have the potential to be low-regret, the analysis finds the benefits vary strongly across the range of climate projections, and with the assumptions on capital costs versus operating savings. There have also been studies at Member State and local level that have assessed costs of passive and retrofit options (e.g. van Ierland et al., 2006; Arup, 2008). There are some indicative studies of adaptation costs emerging on the supply side, with some estimates of adaptation costs for addressing threats to cooling in thermal power plants that indicate potentially high costs for Western Europe (as reported in CEPS/ZEW, 2010).

Health sector

In the health sector, there is good information (including ex post data) on the costs of some early adaptation responses, which indicate that these are a low-cost response for addressing early heat-related mortality. For example, there is good ex-post information on the costs of heat-alert schemes (Ebi et al., 2004; ONERC, 2009; WHO, 2009), which reports these are relatively inexpensive to set up (with estimates ranging from under EUR 1 m to up to around EUR 10 m per scheme, depending on the cost categories included, with upper estimates including costs of additional medical personnel and/or resource costs, noting that future annual costs will rise as the systems are triggered more frequently with climate change). A number of these systems have been activated and provide ex-post information on their effectiveness in term of benefits. Although quantified information is often not available on these systems, data from outside Europe (Ebi et al., 2004) report extremely high

benefit-to-cost ratios. There is much less information on the costs of adaptation for other risks, although the limited information available suggests that many early public health-based adaptation measures are relatively cost-effective, and/or have high benefit-to-cost ratios (Kovats, 2009). However, some options (e.g. large-scale vaccination programmes, infrastructure such as cool rooms, or new waste water treatment) increase costs significantly (Kovats, 2009: Watkiss and Hunt, 2010). For example, Michelon et al., (2005) cite a figure of more than EUR 150 m being invested for additional staff and cool rooms in elderly residential homes in France. As impacts evolve over time, and risks become more cross-sectoral in nature (e.g. requiring intervention from outside traditional public health measures), the cost of adaptation could rise significantly, due to the need for larger capital investment (Watkiss and Hunt, 2010). Similarly, high costs have been projected in Sweden (SCCV, 2007) for the increased infrastructure costs for waste water treatment that can address climate change risks.

Agricultural sector
In the agricultural sector, there has been considerable progress in moving from farm-level adaptation up to larger aggregation levels. Crop modelling studies (e.g. Watkiss, 2011) show high economic benefits from adaptation and relatively low costs (for fertiliser and irrigation), although some of the literature estimates higher costs at the regional level (e.g. Bosello et al., 2009), and even at the local level.

Transport sector
In the transport sector, there are some cost estimates of the additional cost of adaptation for transport infrastructure (Jochem and Schade, 2009), and a number of emerging sector assessments at Member State level (e.g. SCCV, 2007). There are also sectoral estimates emerging for adaptation costs for specific transport modes (e.g. for river transport).

Tourism sector
For tourism, there are studies (OECD, 2007) that assess the costs of adaptation in the Alps, and the costs of additional snow machines and their increased use in order to cope with a decline in snow volumes in the lower altitude ski resorts. However, these measures are often considered as maladaptation (EEA, 2009).

Biodiversity and ecosystem services
Finally, while there are an emerging number of studies on adaptation for the natural environment, biodiversity and ecosystem services, there remain few assessments of adaptation costs and benefits in this area. Likewise, the coverage of industry and business is primarily focused on qualitative assessments.

Methodological caveats
Looking across the sectors above, a number of important caveats must be highlighted. The coverage of adaptation costs is partial, reflecting only a sub-set of possible risks and impacts from climate change (reflecting the evidence based on impacts and the costs of inaction). Many of the results are the outputs of scenario-based impact assessments, and so are produced for defined scenarios, i.e. where a defined scale of future change is assumed. In reality, there is a very wide range of climate risks across the different socio-economic scenarios and climate model projections, which influence the level of adaptation. Related to this concern, it is important to assess whether results are reported for adaptation to the effects of climate change alone, or for climate and socio-economic change together. Many of the assessments focus on technical adaptation, investigating a small set of available options, and the estimates generally ignore policy and transaction costs. There are also major issues with the reporting and adjustment of economic values in different time periods, and with whether future values are presented as discounted or present values. Finally, the costs are defined by the framework of analysis and the objectives set for adaptation, e.g. whether cost-benefit or cost-effectiveness analysis is used, and for the latter, the targets (e.g. level of risk protection) set.

A4.2 Economic approaches for decision-making under uncertainty

A key focus in the adaptation literature in recent years has been the recognition that adaptation is a process that is characterised by uncertainty (defined in the broadest sense), and it is difficult to predict when adaptation is required and how much adaptation is needed. This has refocused the analysis of adaptation so that it starts with the current risks and situation and also considers wider drivers, grounding the assessment in the policy and institutional context.

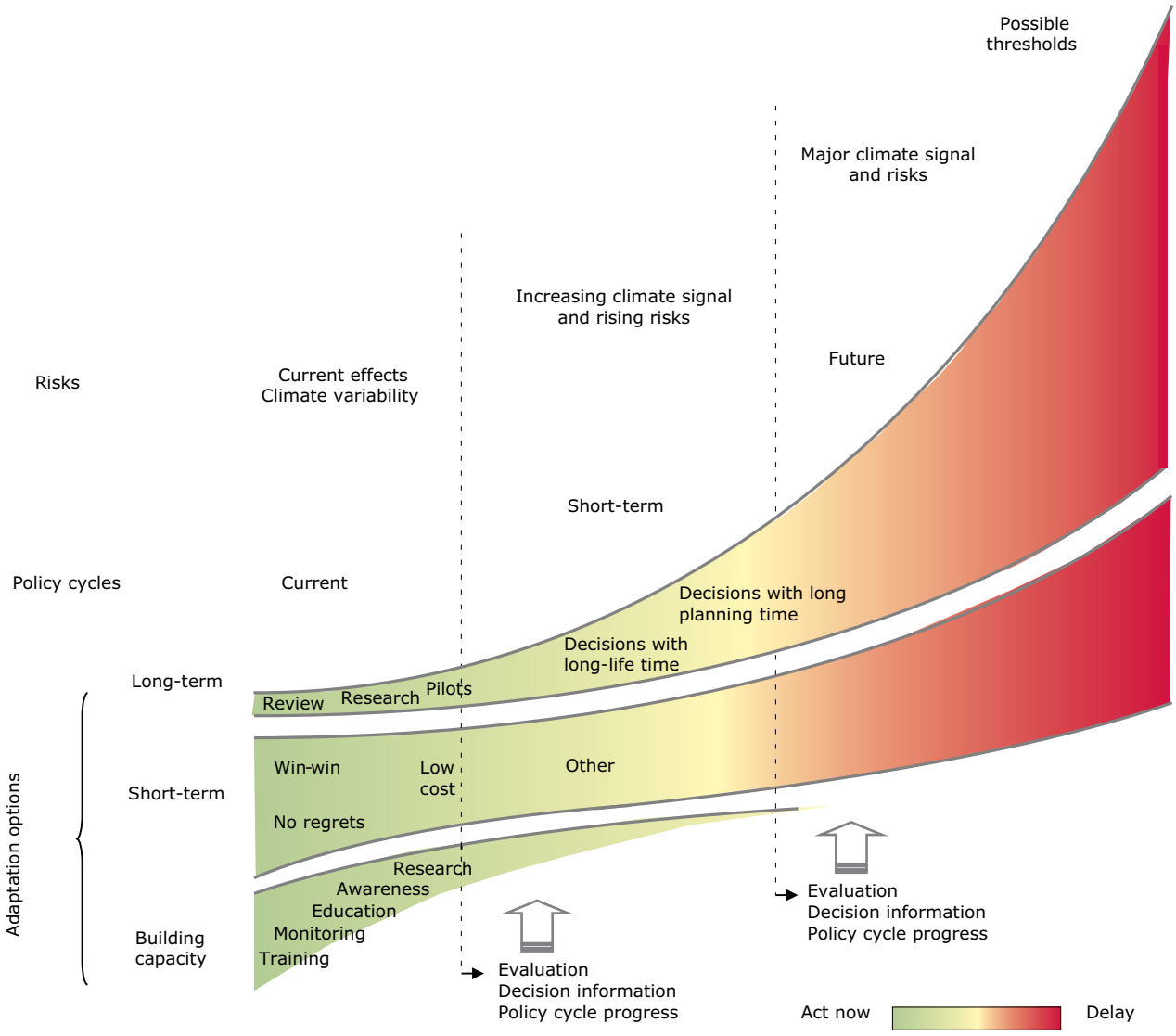
This has led to an emerging focus on decision making under uncertainty, and iterative adaptive management (iterative risk assessment), which provides a framework for working in the context of uncertainty. However, iterative adaptive management also presents challenges for economic assessment, especially within classical scenario-driven impact assessments. To do this

economic assessment under iterative adaptive management, adaptation pathways are built up that address the evolving nature of risks over time, allowing for new evidence to be iteratively incorporated in decision making and adaptation policymaking over time (see details in Section 4.2.1). The following puts an economics focus to it.

A generic example of an adaptation pathway is shown in Figure A4.1. The starting point is the 'risks' (at the top of the figure), which potentially increase over time, but will vary depending on future scenarios and outcomes. These are then placed in the context of the sequential cycle of risks and vulnerabilities assessments and national policy cycles. Together, these provide the basis for an iterative cycle that allows subsequent information to be included to help redirect and inform adaptation over time. The diagram also shows the flow of adaptation options over time. On the left — in green — are the early priorities. These are primarily focused on capacity building, no regret options and early planning for long-term decisions. Early planning for long-term decisions aims to undertake early steps to allow later decisions, thus enhancing flexibility and avoiding lock-in.

Over time, other options can be introduced once better information is available. It is important to note that many of the options in later periods will involve higher costs or more radical solutions, and may only be applicable if future risks are high.

Figure A4.1 Generic adaptation pathway



Source: Watkiss and Hunt, 2011.

The need to recognise and work with uncertainty in adaptation — as part of integrated and sustainable policies — requires an iterative and flexible approach. This is recognised in the mainstream adaptation literature, and is now starting to be adopted in the consideration of adaptation costs and benefits. As a result, there has been a greater focus on capacity building, low-regret and synergy options, and iterative adaptation pathways, which involve a much wider suite of processes and options for adaptation, focusing on robustness and resilience. Therefore the following elements are also key to adaptation policy action from an economic perspective (Fankhauser and Soare, 2013):

- Supporting adaptive capacity as adaptation is a process as well as an outcome,
- Identifying win-win or low-regret measures justified by current climate change or socio-economic developments, and ancillary benefits, and
- Identifying those long-term issues requiring early pro-active investigation (though not necessarily firm action) or where long life/ lead-times or irreversibility is involved. Option valuation can support taking decision in such context.

Adaptation pathways and adaptive management approaches have been exemplified by the Thames Estuary 2100 project (EA, 2009b; 2011; see Section 2.5.2) and the Dutch Delta Programme in the Netherlands (see Section 2.5.3), and the approach is now also being considered for national adaptation planning.

These approaches require a suite of new decision support tools that can address different elements of uncertainty. A summary list of the tools for economic analysis and decision making under uncertainty is presented in Table A4.1 below. Note that while a range of tools are presented, these are not mutually exclusive and are the subject of further research to support their progressive use in the implementation of adaptation.

A4.3 Methods for assessing adaptation costs and benefits

Over the last few years, a wide range of methodologies have emerged for assessing the costs (and benefits) of adaptation, shown in the Table A4.2 below. These use different metrics, modelling approaches and assumptions, and often focus on different time periods.

No one method is right or wrong — their usefulness depends on the objectives of any given assessment. Different methods may be more or less appropriate according to whether they are aimed at providing headline information, scoping possible options, looking at the costs of climate proofing, or undertaking detailed economic assessment of specific plans or projects.

Table A4.1 Adaptation decision support tools for economic analysis and decision-making under uncertainty

	Decision / Decision support tool	Brief description	Usefulness and limitations in climate adaptation context	Principal references
Traditional appraisal	**Social Cost-Benefit Analysis (CBA)**	CBA values all relevant costs and benefits to government and society of all options, and estimates the net benefits/costs in monetary terms. CBA aims to directly compare costs and benefits, allowing comparisons within and across sectors.	Most useful when: • Climate risk probabilities known; • Climate sensitivity likely to be small compared to total costs/ benefits; • Good quality data exists for major cost/benefit components.	The Green Book, HMT, 2007; Metroeconomica, 2004; Ranger et. al., 2010
	Social Cost-Effectiveness Analysis (CEA)	CEA compares the relative costs of different options, and can assess alternative ways of producing the same or similar outputs, identifying least-cost outcomes using cost-curves.	Most useful when: • As for CBA, but also application for non-monetary metrics (e.g. health); • Agreement on sectoral social objective (e.g. acceptable risks of flooding).	Watkiss et. al., 2009; Metroeconomica, 2004
Economic decision making under uncertainty	**Real Options Analysis (ROA)**	ROA extends the principles of CBA to allow economic analysis of learning, delay and future option values, thus providing context to decisions under uncertainty. It can also provide economic analysis on the benefits of flexibility and value information that reduces the uncertainty relating to climate risks.	Most useful for: • Large irreversible capital intensive investment, with potential for learning (especially when long decision/construction lifetime; Climate risk probabilities are known.	IEA, 2007; Green Book Supplementary Guidance, HMT, 2009
	Informal ROA (decision trees)	Informal application of the decision trees used in ROA with formal economic appraisal (rather than formalised ROA analysis).	As above, but wider application due to less focus on probabilities, and economic option value.	EA, 2009 for Thames Estuary2100
	Portfolio Analysis (PA)	PA allows an explicit trade-off to be made between the return – measured e.g. in net benefit terms (from CBA) — and the uncertainty of that return — measured by the variance — of alternative combinations (portfolios) of adaptation options, under alternative climate change projections.	Most useful when: • As for CBA; • A number of adaptation actions are likely to be complementary in reducing climate risks.	Crowe and Parker, 2008
	Robust Decision Making (RDM)	RDM quantifies the trade-offs implied by adopting adaptation options that address possible vulnerabilities under future uncertainty, compared with other criteria such as economic efficiency, stress testing options against large numbers of future scenarios.	Most useful when: • Scenarios of alternative climate, socio-economic and vulnerability futures can be constructed, and data for their characterisation is available.	Groves and Lempert, 2007
	Risk-Based Rules (RBR)	Ranking, (ordinal or cardinal), guided by risk attitude of decision-maker. Includes e.g. Maximin and Minimax Regret rules.	Most useful when: • Climate risk probabilities not well established, or do not exist; • Degree of social risk appetite agreed.	Willows and Connell (eds.), 2003; Ranger et. al., 2010

Table A4.2 Methodologies for the economic assessment of adaptation

Approach	Description	Examples	Advantages	Limitations
Economic Integrated Assessment Models (IAM)	Global aggregated economic models that assess damage costs of climate change, and costs and benefits of adaptation. Values in future periods, expressed in currencies and equivalent % of GDP, as well as Present Values (PVs).	Global analysis of the costs and benefits of adaptation, with regional breakdown, e.g. Hope, 2009; and de Bruin et al., 2009b.	Provide headline values for raising awareness. Very flexible — wide range of potential outputs, including total PVs. Have been used to provide economic information on global climate policy.	Very aggregated approach with highly theoretical form of adaptation, with no technological detail or consideration of uncertainty (see Patt et al., 2009). Insufficient detail for national or sub-national adaptation planning.
Investment and Financial Flows (IFF)	Financial analysis. Early studies estimate costs of adaptation as the percentage increase against future baseline investment expenditure. More recent national studies assess the increase in marginal cost needed to reduce climate risks to acceptable levels.	Global analysis of adaptation costs presented in UNFCCC, 2007. National studies using detailed approach advanced by UNDP (UNDP, 2009) and now piloted in 19 countries worldwide.	Highlights scale of short-term investment needs for enhancing resilience in sectoral or development plans. Flexible method that can be applied without detailed analysis of climate change.	Often no integral linkage with climate change scenarios. Also no consideration of uncertainty or linkages with practical adaptation decision-making, allthough in principle these can be included.
Computable General Equilibrium models (CGE)	Multi-sectoral and macro-economic analysis for economic costs of climate change, and emerging analysis of adaptation.	National level estimates for autonomous adaptation, e.g. Carraro and Sgobbi (2008), and national planned adaptation costs, e.g. Kemfert (2007). Analysis of sectoral adaptation costs now emerging, e.g. coastal adaptation costs.	Captures cross-sectoral, market linkages in economy-wide models (e.g. global, regional or national scales), including autonomous market adaptation. Can represent global trade effects.	Use aggregated representation of impacts and adaptation. No technical detail. No consideration of uncertainty. Omits non-market effects. Not suitable on its own for detailed national or sectoral-based planning.
Impact-assessment — scenario based	Projected future physical impacts and associated welfare costs of climate change derived, using climate model outputs and sectoral impact functions/models. This is complemented by comparison of costs and benefits of selected adaptation options.	Global scale, European scale (e.g. Watkiss et al., 2011 for a wider range of sectors). National sector specific scale (e.g. UK Flooding (Evans et al., 2004)).	Sector-specific analysis at regional, national or sub-national scale. Provides physical impacts as well as welfare values. Can capture non-market sectors.	Not able to represent cross-sectoral, economy-wide effects. Tends to treat adaptation as a menu of hard (engineering-) adaptation options to respond to specific defined scenarios. Medium- to long-term focus of impact assessment may mean less relevance for short-term policy.

Table A4.2 Methodologies for the economic assessment of adaptation (cont.)

Approach	Description	Examples	Advantages	Limitations
Impact assessment — extreme weather events	Variation of IA approach above, using historic damage-loss relationships from extreme events applied to future projections of such events. Adaptation costs estimated on basis of replacement expenditures or analysis of response options.	Sub-national and sector applications.	Allow consideration of future climate variability, in addition to future trends. Provides information on short-term priorities (associated with current climate extremes).	May be inappropriate to apply historical relationships to future socio-economic conditions. Robustness limited by the current high uncertainty in predicting future extremes.
Risk assessment	Risk-based variations include probabilistic analysis and thresholds.	Widely applied in flood risk management analysis (coastal/ river) within cost-effectiveness framework for defined levels of protection.	As above, but risk-based context allows greater consideration of risk and uncertainty.	Risk-based approach introduces extra dimension of complexity with probabilistic approach.
Impact assessment — econometric based	Variation of IA approaches above. Historical relationships between economic production and climate parameters derived using econometric analysis — and applied to future scenarios — that identify cross-sectoral differences in adaptation measures that deal with current weather sensitivity.	Often applied at the national sector level, notably for agriculture.	Can provide information on economic growth and allow analysis of longer-term effects. Provide greater sophistication with level of detail.	Mostly focused on autonomous or non-specified adaptation. Very simplistic relationships to represent complex parameters. No information on specific attributes.
Adaptation assessments	Economic analysis of adaptive management (including adaptive capacity and iterative (dynamic) adaptation pathway).	National scale methods and applications emerging (e.g. Hunt and Watkiss, 2011) and some sectoral applications for coastal floods (EA, 2009a and 2011).	Stronger focus on immediate adaptation policy needs and decision making under uncertainty. Greater consideration of diversity of adaptation (including soft options) and adaptive capacity.	Resource intensive analysis.

Source: Updated from Watkiss and Hunt, 2010.

References

Aaheim, A., Dokken, T., Hochrainer, S., Hof, A., Jochem, E., Mechler, R., van Vuuren, D.P., Neufeldt, H., Wei, T., 2010, 'National responsibilities for adaptation strategies: lessons from four modelling frameworks', Part I, Chapter 4. In: *Making Climate Change Work for Us. European perspectives of adaptation and mitigation strategies*. Editors: Mike Hulme and Henry Neufeldt. Published by Cambridge University Press.

ADEME, 2012, *Élaborer et mettre en œuvre une stratégie ou un plan d'action d'adaptation dans un territoire – Éléments méthodologiques tirés de l'expérience internationale, Adaptation au Changement Climatique*, Agence de L'Environnement et de la Maîtrise de l'Energie (ADEME).

Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B., Takahashi, K., 2007, 'Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability'. In: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson (Eds.), *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (717–743). Cambridge University Press, Cambridge, the United Kingdom.

Adger, W.N., Vincent, K., 2005, 'Uncertainty in adaptive capacity', *External Geophysics, Climate and Environment* (337/4) 399–410.

Agrawala, S., Bosello, F., Carraro, C., de Cian, E. and Lanzi, E., 2011, 'Adapting to Climate Change: Costs, Benefits, and Modelling Approaches', *International Review of Environmental and Resource Economics* (5) 245–284.

Agrawala, S. and Frankhauser, S. (Eds.), 2008, *Economic Aspects of Adaptation to Climate Change. Costs, Benefits and Polidy Instruments*. OECD, Paris, p. 138.

Ahtonen, A., Chiorean-Sime, S., Schneider, C. and Sudbury, I., 2012, 'The climate is changing – is Europe ready? Building a common approach to adaptation', *EPC Issue paper* No. 70, European Policy Centre.

Albrechts, L., 2004, 'Strategic (spatial) planning reexamined', *Environment and Planning B: Planning and Design* (31) 743–758.

Arup, 2008, *Your home in a changing climate. Report for the Three Regions Climate Change Group*, http://www.london.gov.uk/trccg/docs/pub1.pdf.

Bavarian State Ministry of the Environment and Public Health, 2009, *Bavarian Climate Programme 2020*, 24 pp.

Berry P. (editor), 2009, *Biodiversity in the Balance — Mitigation and Adaptation Conflicts and Synergies*, Pensoft.

Biesbroek, G.R., Swart, R.J., Carter, T.R., Cowan, C., Henrichs, T., Mela, H., Morecroft, M.D., Rey, D., 2010, 'Europe adapts to climate change: Comparing National Adaptation Strategies', *Global Environmental Change* (20/3) 440–450.

BMVBS, 2010, *National strategies of European countries for climate change adaptation: A review from a spatial planning and territorial development perspective*. BMVBS-Online-Publikation 21/2010.

Bosello, F., Nicholls, R.J., Richards, J., Roson, R. and Tol, R.S.J., 2012, 'Economic impacts of climate change in Europe: sea-level rise', *Climatic Change* (112/1) 63–81, doi: 10.1007/s10584-011-0340-1.

Bosello, F., Carraro, C., De Cian, E., 2009, *An Analysis of Adaptation as a Response to Climate Change*, Working Paper Department of Economics, Ca' Fosari University of Venice, No. 26/WP/2009.

Broekx, S., Smets, S., Liekens, I., Bulckaen, ., Nocker, L., 2011, 'Designing a long-term flood risk management plan for the Scheldt estuary using a risk-based approach', *Natural Hazards* (57/2) 245–266.

Brown, S., Nicholls, R.J., Vafeidis, A., Hinkel, J., and Watkiss, P., 2011, 'The Impacts and Economic Costs of Sea-Level Rise in Europe and the Costs and Benefits of Adaptation. Summary of Results from the EC RTD ClimateCost Project'. In: Watkiss, P (Editor), *The ClimateCost Project. Final Report. Volume 1: Europe*.

Published by the Stockholm Environment Institute, Sweden. ISBN 978-91-86125-35-6.

Brown, A., Gawith, M., Lonsdale, K., Pringle, P., 2011, *Managing adaptation: linking theory and practice*. UKCIP, the United Kingdom.

Burton, I., Diringer, E., Smith, J., 2006, *Adaptation to Climate Change: International Policy Options*, prepared for the Pew Center on Global Climate Change.

Carraro, C. and Sgobbi, A., 2008, *Climate Change Impacts and Adaptation Strategies in Italy: An Economic Assessment*.

CEPS/ZEW, 2010, *The Fiscal Implications Of Climate Change Adaptation*. Centre for European Policy Studies (CEPS) and Centre for European Economic Research (ZEW). Report to ECFIN/E/2008/008. Final Report. Part I and Part 2.

Charron, N., Dahlström, C. and Lapuente, V., 2012, 'No law without a state', *Journal of Comparative Economics* (40) 176–193.

Chatry, C., Le Quentrec, M., Laurens, D., Le Gallou, J.Y. Lafitte, J.J. Creuchet, B. and Grelu, J., 2010, *Changement climatique et extension des zones sensibles aux feux de forêts*, Rapport de la mission interministérielle 'Changement climatique et extension des zones sensibles aux feux de forêts', ONERC, http://www.ladocumentationfrancaise.fr/var/storage/rapports-publics/104000494/0000.pdf.

Clar, C., Prutsch, A. and Steurer, R., 2012, *Barriers and guidelines in adaptation policy making: Taking stock and analysing congruence*. Presented at the symposium 'The Governance of Adaptation', 22–23 March, Amsterdam.

Cochran, Ian, 2009, Climate Change Vulnerabilities And Adaptation Possibilities For Transport Infrastructures In France, No. 18, CDC Climat Research.

COWI, 2012, *Skybrudsplan og strategi — Københavns kommune, Frederiksberg kommune*, Copenhagen.

De Bruin, K., Dellink, R.B., Ruijs, A., Bolwidt, L, van Buuren, A., Graveland, J., de Groot, R.S., Kuikman, P.J., Reinhard, S., Roetter, R.P., Tassone, V.C., Verhagen, A. and van Ierland, E.C., 2009, 'Adapting to climate change in The Netherlands: an inventory of climate adaptation options and ranking of alternatives, *Climatic change* (95) 23–45, doi:10.1007/s10584-009-9576-4.

de Bruin, K., Dellink, R. and Agrawala, S., 2009, *Economic Aspects of Adaptation to Climate Change: Integrated Assessment Modelling of Adaptation Costs and Benefits*, OECD Environment Working Papers, No. 6, OECD.

de Bruin, K.C., Dellink, R.B. and Tol, R.S.J., 2009, 'AD-DICE: An implementation of adaptation in the DICE model', *Climatic Change* (95/1–2) 63–81.

De Neufville, R. and Odoni, A., 2003, *Airport Systems: Planning, Design, and Management*, New York, McGraw-Hill.

Defra, 2011, *The UK Climate Change Risk Assessment (CCRA)*. Published by the Department for Environment, Food and Rural Affairs. London, the United Kingdom.

Defra, 2010, *Measuring Adaptation to Climate Change – A Proposed Approach*, http://archive.defra.gov.uk/environment/climate/documents/100219-measuring-adapt.pdf.

DEFRA, 2012a, *UK Climate Change Risk Assessment: Government Report*.

DEFRA, 2012b, *UK Climate Change Risk Assessment 2012 Evidence Report*.

DEFRA, 2012c, *Adapting to Climate Change — Future Worlds images*, www.defra.gov.uk/adaptation.

Delta Commissie, 2008, *Working together with Water. A living land builds for its future. Findings of the Deltacommissie*. DeltaCommissie.

Delta Programme Commission, 2010, Working on the delta. Investing in a safe and attractive Netherlands, now and tomorrow. Ministry of Transport, Public Works and Water Management, Ministry of Agriculture, Nature and Food Quality, and Ministry of Housing, Spatial Planning and the Environment.

Diermanse, F.L.M., Kwadijk, J.C.J., Beckers, J.V.L., Crebas, J.I., 2010, 'Statistical trend analysis of annual maximum discharges of the rhine and meuse rivers'. In: *Proceedings of British hydrological society, 3rd international conference. role of hydrology in managing consequences of a changing global environment*, http://www.ceg.ncl.ac.uk/bhs2010.

Dumollard, G. and Leseur, A. 2011, 'Drawing up a national climate change adaptation policy: Feedback from five European case studies. Climate Report'. *Research on the economics of climate change*. No 27.

EA, 2009a, *Investing for the Future Flood and Coastal Risk Management in England — A Long-term Investment Strategy*. Published by Environment Agency, Bristol, the United Kingdom.

EA, 2009b, *Thames Estuary 2100. Managing flood risk through London and the Thames estuary*. TE2100 Plan

Consultation Document April 2009. Published by Environment Agency, Bristol, the United Kingdom.

EA, 2011, *Thames Estuary 2100 (TE2100) Strategic Outline Programme*. Published by Environment Agency, Bristol, the United Kingdom.

Ebi, K.L., Teisberg, T.J., Kalkstein, L.S., Robinson, L. and R.F. Weiher, 2004, 'Heat Watch/Warning Systems Save Lives: Estimated Cost and Benefits for Philadelphia 1995–98', *Bulletin of the American Meteorological Society*.

EC, 2007, Green paper — Adapting to climate change in Europe — options for EU action. SEC(2007) 849, European Commission, Brussels.

EC, 2008, Green Paper on Territorial Cohesion — Turning territorial diversity into strength COM(2008) 616 final, 6 October 2008.

EC, 2009a, White paper — Adapting to climate change: towards a European framework for action (Commission Publication No. COM/2009/0147 final). European Commission, Brussels. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0147:FIN:EN:HTML.

EC, 2009b, *Common implementation strategy for the water framework directive (2000/60/EC). River basin management in a changing climate*. Guidance document No. 24, European Commission, Brussels.

EC, 2010, *Water is for life: How the Water Framework Directive helps safeguard Europe's resources*. European Commission, Luxembourg.

EC, 2011a, Communication — A resource-efficient Europe — Flagship initiative of the Europe 2020 Strategy, COM(2011) 21.

EC, 2011b, *The 2012 Ageing Report: Underlying Assumptions and Projection Methodologies,* European Economy No. 4/2011, European Commission, Brussels.

EC, 2012, 'Proposal For A Decision Of The European Parliament And Of The Council On A General Union Environment Action Programme To 2020 'Living well, within the limits of our planet'', COM(2012) 710 final.

EEA, 2007, *Climate change: the cost of inaction and the cost of adaptation*, EEA Technical report No 13/2007, Published December 2007. Paul Watkiss, Francesco Bosello, Barbara Buchner, Michela Catenacci, Alessandra Goria, Onno Kuik and Etem Karakaya, European Environment Agency.

EEA, 2009, *Regional climate change and adaptation — The Alps facing the challenge of changing water resources*, EEA Report No 8/2009, European Environment Agency.

EEA, 2010a, *The European environment: state and outlook 2010: Thematic assessment – Water resources: Quantity and flows*, European Environment Agency.

EEA, 2010b, *The European environment — state and outlook 2010: adapting to climate change*, European Environment Agency.

EEA, 2010c, *The European environment — state and outlook 2010: assessment of global megatrends*, European Environment Agency.

EEA, 2011, *Green infrastructure and territorial cohesion*, EEA Technical report No 18/2011, European Environment Agency.

EEA, 2012a, *Towards efficient use of water resources in Europe*, EEA Report No 1/2012, European Environment Agency.

EEA, 2012b, *Urban adaptation to climate change in Europe — Challenges and opportunities for cities together with supportive national and European policies*, EEA Report No 2/2012, European Environment Agency.

EEA, 2012c, *Climate change, impacts and vulnerability in Europe 2012 — An indicator-based report,* EEA Report No 12/2012, European Environment Agency.

EEA, 2012d, *Environmental indicator report 2012 — Ecosystem resilience and resource efficiency in a green economy in Europe*, European Environment Agency.

Egan, T., 1998, 'The story so far'. In: *The future use of Cutaway Bogs — Proceedings from the first comprehensive conference on cutaway bogland rehabilitation*, Cutaway Bogs Conference 1998, Kilcormac, Co. Offaly, Ireland.

Egan, T., 1999, *A Landscape Uncloaked: Lough Boora Parklands — The National Centre of Cutaway Boglands Rehabilitation in Ireland*. The Heritage Council, Policies and Priorities for Ireland's Landscape Conference, Tullamore, Co. Offaly, Ireland, April 1999.

EUROCONTROL, 2008, *Challenges of Growth 2008 – Summary Report*.

EUROCONTROL, 2009, *Challenges of growth' environmental update study*, Environment Technical Report.

EUROCONTROL, 2010, *'Challenges of growth' environmental update study — Climate Adaptation Case-Studies*.

EUROCONTROL, 2011, 'Challenges of growth' environmental update study — Climate Adaptation Case-Studies: EUROCONTROL Commentary.

EUROSAI-WGEA, 2012, *Adaptation to climate change — are governments prepared?, A cooperative audit*, European Organisation of Supreme Audit Institutions — Working Group on Environmental Auditing (EUROSAI WGEA).

EUSTAFOR, 2010, *European Forestry in the Face of Climate Change*, EUSTAFOR Guidelines, pp. 32.

Evans, E.P., Simm, J.D., Thorne, C.R., Arnell, N.W., Ashley, R.M., Hess, T.M., Lane, S.N., Morris, J., Nicholls, R.J., Penning-Rowsell, E.C., Reynard, N.S., Saul, A.J., Tapsell, S.M., Watkinson, A.R., Wheater, H.S., 2008, *An update of the Foresight Future Flooding 2004 qualitative risk analysis*. Cabinet Office, London.

Evans, E., Ashley, R., Hall, J., Penning-Rowsell, E., Saul, A., Sayers P., Thorne, C. and Watkinson, A., 2004, *Foresight. Future Flooding. Scientific Summary: Volumes I and II*. Office of Science and Technology, London.

Fankhauser, S., 2009, *A perspective paper on adaptation as a response to climate change*. Copenhagen Consensus Center, Denmark.

Fankhauser, S. and Soare, R., 2013, *An Economic Approach to Adaptation: Illustrations from Europe, Climatic Change,* forthcoming.

Feehan, J., Kaye, B., 1998, 'Creating the space for a new Irish wilderness'. In: *The future use of Cutaway Bogs — Proceedings from the first comprehensive conference on cutaway bogland rehabilitation*, Cutaway Bogs Conference 1998, Kilcormac, Co. Offaly, Ireland.

Feehan, J., O'Donovan, G., Renou-Wilson, F., Wilson, D., 2008, *The Bogs of Ireland — An Introduction to the Natural, Cultural and Industrial Heritage of Irish Peatlands (Revised Edition)*. University College Dublin, School of Biology and Environmental Science.

Feyen, L. and Watkiss, P., 2011, 'Technical Policy Briefing Note 3. The Impacts and Economic Costs of River Floods in Europe, and the Costs and Benefits of Adaptation. Results from the EC RTD ClimateCost Project'. In: Watkiss, P (Editor), *The ClimateCost Project. Final Report*. Published by the Stockholm Environment Institute, Sweden. ISBN 978-91-86125-35-6.

Firus, K., Fleischhauer, M., Greiving, S., Stickler, T., D'Andrea, A., Ferranti, C., Flex, F. Kobotschnig, G., Fangucci, G., Scheibel, M., Ebers, M., Sereinig, N., Malvati, P., Grifoni, P., Bagnini, S., Guzzo, T., Vitale, V., Wanczura, S., 2011a, *Integrative flood risk governance approach for improvement of risk awareness and increased public participation(IMRA), Final Report*. ERA-Net CRUE reference code: IMRA IV-3.2, 136 pp. incl. Appendix. Rome, Dortmund, Wuppertal, Vienna, Klagenfurt.

Firus, K., Fleischhauer, M., Greiving, S., Grifoni, P., Stickler, T., 2011b, *Planning and implementing communication and public participation processes in flood risk management- Procedural guidelines and toolbox of methods*, Reference code: IMRA: IV-4.1.4.

Flörke, M., Wimmer, F., Laaser, C., Vidaurre, R., Tröltzsch, J., Dworak, T., Stein, U., Marinova, N., Jaspers, F., Ludwig, F., Swart, R., Giupponi, C., Bosello, F., Mysiak, J., 2012, *Final Report for the project Climate Adaptation – modelling water scenarios and sectoral impacts,* Contract N° DG ENV.D.2/SER/2009/0034.

Ford, J., Berrang-Ford, L., Paterson, J., 2011, 'A systematic review of observed climate change adaptation in developed nations', *Climatic Change* (106) 327–336.

Forest Europe, UNECE and FAO, 2011, *State of Europe's forests, 2011: status & trends in sustainable forest management in Europe*, Ministerial Conference on the Protection of Forests in Europe, Forest Europe, Liaison Unit Oslo, Aas, Norway.

Global Electricity Initiative, 2011, *Resilience and adaptation to climate change: electricity utilities' perspective*.

Gordo, J., Calama, R., Rojo, L.I., Madrigal, G., Álvarez, D., Mutke, S., Montero, G., Finat, L., 2009, *Experiencias de clareos en masas de Pinus pinea L. en la Meseta Norte*, 5 º Congreso Forestal Español.

Greiving, S. (ed.) 2011, *ESPON Climate — Climate Change and Territorial Effects on Regions and Local Economies. Applied Research 2013/1/4. Final Report. Version 31/5/2011*. Main Report. Dortmund 2011.

Grothmann, T., 2011, 'Governance recommendations for adaptation in European urban regions: Results from five case studies and a European expert survey'. In: K. Otto-Zimmermann (ed.), *Resilient Cities — Cities and Adaptation to Climate Change — Proceedings of the Global Forum 2010* (167–175). Hamburg: Springer.

Haasnoot, M., Middelkoop, H., van Beek, E. & van Deursen, W.P.A., 2011, 'A method to develop sustainable water management strategies for an

uncertain future', *Sustainable Development* (19) 369–381, doi:10.1002/sd.438.

Haasnoot, M., Middelkoop, H., Offermans, A., Van Beek, E. & van Deursen, W.P.A., 2012a, 'Exploring pathways for sustainable water management in river deltas in a changing environment', *Climatic Change*. doi:10.1007/s10584-012-0444-2.

Haasnoot, M., Kwakkel, J.H., Walker, W.E., 2012b, *Designing adaptive policy pathways for sustainable water management under uncertainty: Lessons learned from two case. Third international engineering system symposium*. CESUN 2012, Delft University of Technology, 18–20 June 2012.

Haasnoot, M., Kwakkel, J.H., Walker, W.E., 2012c, *Dynamic Adaptive Policy Pathways: A New Method for Crafting Robust Decisions for a Deeply Uncertain World.* Submitted.

Hallegatte, S., 2009, 'Strategies to adapt to an uncertain climate change', *Global Environmental Change* (19) 240–247.

Hanewinkel, M., Dominik, A., Cullmann, Schelhaas, M.-J., Nabuurs, G.-J. and Zimmermann, N.E., 2012, Climate change may cause severe loss in the economic value of European forest land, Nature Climate Change, doi:10.1038/Nclimate1687.

Harley, M. and J. Van Minnen, 2009, *Development of Adaptation Indicators*, EEA/ETC ACC Technical Paper 2009/6, European Topic Centre on Air and Climate Change.

Hinkel, J. and Klein, R.J.T., 2009, 'The DINAS-COAST project: Developing a tool for the dynamic and interactive assessment of coastal vulnerability', *Global Environ Change* (19/3) 384–395.

Hinkel, J., Nicholls, R.J., Vafeidis, A.T., Tol, R.S.J., Avagianou, T., 2010, 'Assessing risk of and adaptation to sea-level rise in the European Union: An application of DIVA', *Mitig Adaptation Strategies for Glob Change* (15) 703–719, doi:710.1007/s11027-11010-19237-y.

HM Government, 2010, *Climate change: Taking action. Delivering the Low Carbon Transition Plan and preparing for a changing climate*. Crown Copyright, the United Kingdom.

Holm, Audrey, 2010, *Infrastructures In The Face Of Climate Change: What Implications For Long-Term Investors?*, No. 22, CDC Climat Research.

Hope, C., 2009b, 'The Costs and Benefits of Adaptation'. Chapter 8 in Parry, M.L., Arnell, N., Berry, P., Dodman, D., Fankhauser, S., Hope, C., Kovats, S., Nicholls, R., Satterthwaite, D., Tiffin, R., Wheeler, T., 2009, *Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates*, International Institute for Environment and Development and Grantham Institute for Climate Change, London.

Horrocks, L., Beckford, J., Hodgson, N., Downing, C., Davey, R. and O'Sullivan, A., 2010, *Adapting the ICT Sector to the Impacts of Climate Change – Final Report*, Defra contract number RMP5604. AEA group. Published by Defra.

Hudeková, Z. and Tvrdoň, M., 2011, *Adaptation action plan Bratislava — Executive summary, GraBS project,* http://www.grabs-eu.org/downloads/AAP_ Executive_ summary_Bratislava.pdf.

Hulsman, H., Maarse, M., 2010, *Dutch experiences with Green Adaptation in Water Management*. Deltares publication 1203218.

Hulsman, H., Van der Meulen, M., Van Wesenbeeck, B., 2011, *Green Adaptation — making use of ecosystems services for infrastructure solutions in developing countries*. Deltares publication 1204587.

Hungarian Presidency, 2011, *Impact of the European demographic trends on regional and urban development*, Synthetic report, Prepared for the Urban Development Group. Hungarian Presidency of the Council of the European Union.

Hunt, A. and Watkiss, P., 2011, *The UK Adaptation Economic Assessment. Methodology Report*. Report to Defra as part of the UK Climate Change Risk Assessment. Published by Defra.

IIASA, 2012, SSP Database (version 0.93):.https://secure.iiasa.ac.at/web-apps/ene/SspDb (accessed 15 October 2012).

IPCC, 2007, *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.

IPCC, 2007, *Climate Change 2007: Synthesis Report*. Cambridge University Press, the United Kingdom.

IPCC, 2011, *Special Report — Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX).*

Irish Peatland Conservation Council (IPCC) — *Action for Bogs and Wildlife in Ireland. Restoration of Industrial Cutaway Peatlands*, http://www.ipcc.ie/advice/peatland-management-diy-tool-kit/restoration-of-industrial-cutaway-peatlands.

Irish Peatland Conservation Council (IPCC) — *Action for Bogs and Wildlife in Ireland. Climate Change and Irish Peatlands*, http://www.ipcc.ie/peatland-action-plan/climate-change-and-irishpeatlands.

Jeuken, A., te Linde, A., Woelders, L., Kwadijk, J., , 2010, *On the use of water scenarios in the Dutch Delta Programme*, Bundesanstalt für Gewässerkunde, Veranstaltungen, Deltares.

Jeuken, A. and T. Reeder, 2011, *Short-term decision making and long-term strategies: how to adapt to uncertain climate change. Examples from the Thames Estuary and the Dutch Rhine-Meuse Delta, Water Governance 1*.

Jochem, E.; Schade, W., 2009, *Deliverable M1.2: Report of the Reference and 2°C Scenario for Europe*, Deliverable of the ADAM Project, Fraunhofer Institute for Systems and Innovation Research (ISI).

Jones, L., 2010, *Overcoming social barriers to adaptation. Overseas Development Institute ODI, Background Note*, 1–7 July 2010.

Jones, M.B., Donnelly, A. and Fabrizio, A., 2006, 'Responses of Irish vegetation to future climate change', *Biology and Environment: Proceedings of the Royal Irish Academy* 106B, 323–334.

Joosten, H., Tapio-Biström, M.-L., Tol, S. (eds.), 2012, *Peatlands — guidance for climate change mitigation through conservation, rehabilitation and sustainable use (second edition)*. Food and Agriculture Organization of the United Nations and Wetlands International: http://www.fao.org/docrep/015/an762e/an762e.pdf.

De Beer, J., Van der Gaag, N., Van der Erf, R., Bauer, R., Fassmann, H., Kupiszewska, D., Kupiszewski, M., Rees, P., Boden, P., Dennett, A., Jasińska, M., Stillwell, J., Wohland, P., De Jong, A., Ter Veer, M., Roto, J., Van Well, L., Heins, F., Bonifazi, C., Gesano, G., 2010, *DEMIFER — Demographic and Migratory Flows Affecting European Regions and Cities, Applied Research 2013/1/3, Final Report — Version 30/09/2010*, ESPON & NIDI, 2010.

Kates, R.W,. Travis, W.R. and Wilbanks, T.J., 2012, 'Transformation adaptation when incremental adaptations to climate change are insufficient', *Proceedings of the National Academy of Sciences* (109/19) 7 156–7 161.

Kazmierczak, A. and Carter, J., 2010, 'Adaptation to climate change using green and blue infrastructure', A database of case studies.

Kemfert, C., 2007, 'Klimawandel kostet die deutsche Volkswirtschaft', *Milliarden*. Nr. 11/2007. 74. Jahrgang/14. März 2007. DIW Berlin.

Klein, R., Huq, S., Denton, F., Downing, T.E., Richels, R.G., Robinson, J.B., Toth, F.L., 2007, *Interrelationships between adaptation and mitigation. Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment.

Kohler-Koch, B. and Rittberger, B., 2006, Review Article: 'The 'Governance Turn' in EU Studies', *Journal of Common Market Studies* (44/s1) 27–49.

Kolström, M., Lindner, M., Vilén, T., Maroschek, M., Seidl, R., Lexer, M. J., Netherer, S., Kremer, A., Delzon, S., Barbati, A., Marchetti, M. and Corona, P., 2011, 'Reviewing the Science and Implementation of Climate Change Adaptation Measures in European Forestry', *Forests* (2/4) 961–982.

Kovats, S, Lloyd, S, Hunt, A and Watkiss, P., 2011, *The Impacts and Economic Costs on Health in Europe and the Costs and Benefits of Adaptation, Results of the EC RTD ClimateCost Project*, Technical Policy Briefing Note 5.

Kovats, S., 2009, 'Adaptation costs for human health'. In: Parry, M., Arnell, N., Berry, P., Dodman, D., Fankhauser, S., Hope, C., Kovats, S., Nicholls, R., Satterthwaite, D., R. Tiffin and T. Wheeler *Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and other recent estimates. IIED and Grantham Institute for Climate Change*, London, http://www.iied.org/pubs/pdfs/11501IIED.pdf.

Kriegler, E., O'Neill, B.C., Hallegatte, S., Kram, T., Lempert, R.J., Moss, R.H. and Wilbanks T., 2012, 'The need for and use of socio-economic scenarios for climate change analysis: A new approach based on shared socio-economic pathways', *Global Environ. Change* (22/4) 807–822.

Kuijken, W., 2010, *The Delta Programme in the Netherlands: the Delta Works of the Future*, http://www.deltacommissaris.nl; http://www.deltacommissaris.nl/english/topics/ Access date 04-04-2013.

Kwadijk, J.C.J., Haasnoot, M., Mulder, J.P.M., Hoogvliet, M.M.C., Jeuken, A.B.M., van der Krogt, R.A.A., van Oostrom, N.G.C., Schelfhout, H.A., van Velzen, E.H., van Waveren, H. and de Wit, M.J.M., 2010, 'Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the

Netherlands', *Wiley Interdisciplinary Reviews: Climate Change*, (1/5), 729–740.

Kwakkel, J.H, Mens, M.J.P., de Jong, A., Wardekker, J.A., Thissen, W.A.H., van der Sluijs, J.P., 2011, *Uncertainty Terminology, Dutch National Research Programme 'Knowledge for Climate' (KvK)*, www.knowledgeforclimate.org.

Kwakkel, J.H., Walker, W.E., Marchau, V.A.W.J., 2010, 'Adaptive airport strategic planning', *European Journal of Transport and Infrastructure Research* (10) 249–273.

Lamhauge, N., Lanzi, E. and S. Agrawala, S., 2012, *Monitoring and Evaluation for Adaptation: Lessons from Development Co-operation Agencies*, OECD Environment Working Papers, No. 38, OECD Publishing, http://dx.doi.org/10.1787/5kg20mj6c2bw-en.

Lamothe, D.N., Neveu, G., Görlach, B., Interwies, E., 2005, *Evaluation of the impacts of floods and associated protection policies. Final Report for EU DG Environment*, Contract nr 07.0501/2004/389669.

Lebel, L., Grothmann, T., Siebenhüner, B., 2010, 'The role of social learning in adaptiveness: insights from water management. International Environmental Agreements', *Politics, Law and Economics* (10/4), 333–353.

Lempert, R.J., Popper, S. and Bankes, S., 2003, *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis*, Santa Monica, California, RAND.

Lexer, M. J. and Seidl, R., 2009, 'Addressing biodiversity in a stakeholder-driven climate change vulnerability assessment of forest management', *Forest Ecology and Management* (258) S158–S167.

Liberatore, A., 1997, 'The Integration of Sustainable Development Objectives into EU Policymaking: Barriers and Prospects'. In: Baker, S; Kousis, M; Richardson, D. and S. Young (Eds.) *The Politics of Sustainable Development: Theory, Policy and Practice within the European Union*. London, Routledge, pp. 108–126.

Lindner, M., Suominen, T., Palosuo, T., Garcia-Gonzalo, J., Verweij, P., Zudin, S. and Päivinen, R., 2010, 'ToSIA—A tool for sustainability impact assessment of forest-wood-chains', *Ecological Modelling (*221/18) 2 197–2 205.

Linham, M.M. and Nichols, R.J., 2012, *Adaptation technologies for coastal erosion and flooding: a review. Proceedings of the Institution of Civil Engineers*, Maritime Engineering 165 Issue MA3, pp. 95–111. http://dx.doi.org/10.1680/maen.2011.29.

Local and Regional Adaptation Partnership (LRAP) 2010, *Adapting to Climate Change*.

Loftus, A.-C., 2011, *Łódź, Poland — River restauration as a catalyst for sustainable urban development*, Case study of the SWITCH project.

Maas, N., Sman, B., Dijkema, G., Bogmans, C., Rietveld, P., Tavasszy, L., 2012, *Mid-Term Review Theme 5 Knowledge for Climate, INCAH — Infrastructure Networks Climate Adaptation and Hotspots*, KfC 61/2012, National Research Programme Knowledge for Climate, http://knowledgeforclimate.climateresearchnetherlands.nl/infrastructurenetworks.

MACIS, 2008, Minimisation of and Adaptation to Climate change Impacts on biodiversity, MACIS project, EU FP6, http://macis-project.net/.

Medarova-Bergstrom, K., Volkery, A., Schiellerup, P., Withana, S. and Baldock, D., 2011, Strategies and instruments for climate proofing the EU budget, IEEP, Brussels.

MEEDDAT, 2005, *Autoroutes et routes nationales — Les autoroutes concédées.*

Merryman, J.H. and R. Pérez-Perdomo. 2007. The Civil Law Tradition: An Introduction to the Legal Systems of Europe and Latin America. Stanford University Press, California.

Metzger M., Rounsevell M., 2011,'A need for planned adaptation to climate change in the wine industry' *Environ. Res. Lett.* (6).

Michelon, T., Magne, P. and Simon-Delaville, F., 2005, 'Lessons of the 2003 heat wave in France and action taken to limit the effects of future heat waves,' in W. Kirch, B. Menne and R. Bertollini (eds) *Extreme Weather Events and Public Health Responses*. Springer-Verlag, pp. 131–140.

Mima, S., Criqui, P., and Watkiss, P., 2011, 'The Impacts and Economic Costs of Climate Change on Enery in Europe. Summary of Results from the EC RTD ClimateCost Project'. In Watkiss, P (Editor), *The ClimateCost Project. Final Report. Volume 1: Europe*. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

Moreno Rodríguez, J. M., Cruz Treviño, A. and Martínez Lope, C., 2005, *Evaluación preliminar de los impactos en España por efecto del cambio climático : proyecto*

ECCE-informe final, Centro de Publicaciones, Ministerio de Medio Ambiente, Madrid.

Moser, Susanne and J.A. Ekstrom, 2010, 'A framework to diagnose barriers to climate change adaptation', *PNAS (*107/51) 22 026-22 031.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010, 'The next generation of scenarios for climate change research and assessment', *Nature* (463), doi:10.1038/nature08823.

Nakicenovic, N., Swart, R. (eds), 2000, *Special Report on Emissions Scenarios (SRES)*. Cambridge University Press, Cambridge.

Newman, P. and Thornley, A., 1996, *Urban Planning in Europe; International competition, national systems and planning projects*. Routledge, London.

OcCC, 2007, *Climate Change and Switzerland in 2050. Expected Impacts on Environment, Society and Economy.*

O'Neill, B.C., Carter, T.R., Ebi, K.L., Edmonds, J., Hallegatte, S., Kemp-Benedict, E., Kriegler, E., Mearns, L., Moss, R., Riahi, K., van Ruijven, B., van Vuuren, D., 2011, *Meeting Report of the Workshop on The Nature and Use of New Socioeconomic Pathways for Climate Change Research*, Boulder, CO, 2–4 November 2011, http://www.isp.ucar.edu/socio-economic-pathways.

OECD, 2007, *Climate change in the European Alps: Adapting winter tourism and natural hazards management*. Organisation for economic Co-operation and development (OECD), Paris.

OECD, 2008, E*conomic Aspects of Adaptation to Climate Change. Costs, Benefits And Policy Instruments*. Edited by Shardul Agrawala and Samuel Fankhauser, OECD Paris.

Offermans, A., 2010, *Learning from the past: The interaction of the social system and the water system in the Netherlands*. Berlin Conference on the Human Dimensions of Global Environmental Change. Berlin.

ONERC, 2009, *Climate change: costs of impacts and lines of adaptation*. Observatoire National sur les Effets du Réchauffement Climatique (National Observatory for the Impacts of Global Warming). Report to the Prime Minister and Parliament, 2009.

ONF, 2011, *La prise en compte des risques liés au changement climatique dans le cadre des aménagements des forêts publiques dans le nord de la France*, Brigitte Landeau séance du 8 juin 2011.

Paavola, J., Adger, W.N., 2006, 'Fair adaptation to climate change', *Ecological Economics* (56) 594–609.

Pahl-Wostl, C., Sendzimir, J., Jeffrey, P., Aerts, J., Berkamp, G. and Cross, K., 2007, 'Managing change towards adaptive water management through social learning', *Ecology and Society* (12/30).

Parry, M., Arnell, N., Berry, P., Dodman, D., Fankhauser, S., Hope, C., Kovats, S., Nicholls, R., Satterthwaite, D., Tiffin, R., Wheeler, T., 2009, Assessing the costs of Adaptation to climate change. A review of the UNFCCC and other recent estimates. International Institute for Environment and Development and Grantham Institute for Climate Change, London.

Patt A, van Vuuren DP, Berkhout F, Aaheim A, Hof AF, Isaac M, Mechler R., 2009, 'Adaptation in integrated assessment modeling: where do we stand?' *Clim Change* (99) 383–402, doi:10.1007/s10584-009-9687-y.

Philip, R., 2011, *Zaragoza, Spain — Reducing water demand and establishing a water saving culture in the city of Zaragoza*. Case study in the SWITCH project.

Pfister, C., 2002, *Am Tag danach. Zur Bewältigung von Naturkatastrophen in der Schweiz 1500–2000*. Hapt Verlag, Bern.

Preston, B., Westaway, R., Yuen, E.J., 2010, 'Climate adaptation planning in practice: an evaluation of adaptation plans from three developed nations', *Mitigation and Adaptation Strategies for Global Change* (16/4) 407–438.

Pringle, P., 2011, *AdaptME: Adaptation monitoring and evaluation*. UKCIP, Oxford, the United Kingdom. http://www.ukcip.org.uk/wordpress/wp-content/AdaptME/AdaptME.pdf

Productivity Commission, 2012, *Barriers to Effective Climate Change Adaptation*, Report, Canberra, http://www.pc.gov.au/_data/assets/pdf_file/0007/116539/climate-change-adaptation-draft-report.pdf.

Prutsch A., Grothmann T., Schauser I., Otto S., McCallum S., 2010, *Guiding principles for adaptation to climate change in Europe*. European Environment Agency ETC/ACC Technical Paper 2010/6; http://acm.eionet.europa.eu/docs/ETCACC_TP_2010_6_guiding_principles_cc_adaptation.pdf.

Quinto, C., 2010, *Versicherungssysteme in Zeiten des Klimawandesl. Elementarschadenversicherung von Gebäuden*. ISBN 978-3-7255-6028-8.

Ranger Nicola, Antony Millner, Simon Dietz, Sam Fankhauser, Ana Lopez and Giovanni Ruta, 2010, Adaptation in the UK: a decision-making process. Policy Briefing Note for the Committee on Climate Change Adaptation Sub-Committee.

Reckien, D., Eisenack, K. and Hoffmann, E., 2009, *Adaption to climate change in the transport sector: the constraining effect of actor-interdependencies*. Potsdam Institute for Climate Impact Research.

Reeder, T. and Ranger, N., 2011, *How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project, World Resources Report*, Washington DC, http://www.worldresourcesreport.org.

Ribeiro, M.M., Losenno, C., Dworak, T., Massey, E., Swart, R., Benzie, M., Laaser, C., 2009, *Design of guidelines for the elaboration of Regional Climate Change Adaptations Strategies, Final Report*, DG Environment.

Rickards, L. and Howden, S.M., 2012, 'Transformational adaptation: agriculture and climate change', *Crop & Pasture Science* (63) 240–250, http://dx.doi.org/10.1071/CP11172.

SCCV, 2007, *Sweden facing climate change — threats and opportunities*. Final report from the Swedish Commission on Climate and Vulnerability, http://www.regeringen.se/sb/d/574/a/96002.

Schönthaler, K., von Andrian-Werburg, S., Wulfert, K., Luthardt, V., Kreinsen, B., Schultz-Sternberg, R., Hommel, R., 2010, *Establishment of an Indicator Concept for the German Strategy on Adaptation to Climate Change*, Climate Change Nr. 07/2010, UBA-FBNr: 001416/E, http://www.uba.de/uba-info-medien-e/4031.html.

Schumacher, U., 2005, *Historic maps promote recent flood risk research — the case of the upper Elbe river*, Leibnitz Institute of Ecological and Regional Development, Dresden.

Sedjo, R.A. 2010, 'Adaptation of forests to climate change'. In: *World bank discussion Paper no. 3.* http://siteresources.worldbank.org/EXTCC/Resources/407863-1229101582229/DCCDP_3Forests.pdf.

Seidl, R., Rammer, W. and Lexer, M. J., 2010, 'Climate change vulnerability of sustainable forest management in the Eastern Alps', *Climatic Change* (106/2) 225–254.

Seppälä, R., Buck, A., Katila, P. and International Union of Forest Research Organizations, 2009, *Adaptation of forests and forest management to changing climate with emphasis on forest health a global assessment report*.

Shaw, R.; Colley, M. and Connell, R., 2007, *Climate change adaptation by design: a guide for sustainable communities*. TCPA, London.

Shirley-Smith, C., Cheeseman, C., Butler, D. and FCIWEM, 2008, 'Sustainability of water management in Zaragoza city', *Water and Environment Journal* (22) 287–296.

Siry, J.P., Cubbage, F.W. and Newman, D.H., 2009, 'Proceedings of the xiii World Forestry Congress', In: *Global Forest Ownership: Implications for Forest Production Management and Protection*, Buenos Aires, Argentina.

Swart, R., Biesbroek, R., Binnerup, S., Carter, T.R., Cowan, C., Henrichs, T., Loquen, S., Mela, H., Morecroft, M., Reese, M., Rey, D., 2009, *Europe Adapts to Climate Change: Comparing National Adaptation Strategies*, PEER Report No 1. Finnish Environment Institute (SYKE), Helsinki: Partnership for European Environmental Research.

Swiss Confederation, 2008, *The Floods of 2005 in Switzerland. Synthesis report on the event analysis,* www.bafu.admin.ch/publikationen/publikation/00819/index.html?lang=en.

Tengö, M. and Belfrage, K., 2004, 'Local management practices for dealing with change and uncertainty: a cross-scale comparison of cases in Sweden and Tanzania', *Ecology and Society* (9/3)..

UNDP, 2005, *Adaptation Policy Frameworks for Climate Change. Developing Strategies, Policies and Measures*, Eds. Bo Lim and Erika Spanger-Siegfried, co-authors Ian Burton, Elizabeth Malone and Saleemul Huq.

UNDP, 2009, *UNDP Methodology Guidebook for the Assessment of Investment and Financial Flows to Address Climate Change*.

UNDP, 2010, *Designing climate change adaptation initiatives. A toolkit for practitioners*. Bureau of Development policy, New York.

UNFCCC, 2007, *Investment and financial flows relevant to the development of an effective and appropriate international response to Climate Change*. United Nations Framework Convention on Climate Change. ISBN 92-9219-042-3.

UNFCCC, 2009, *Potential costs and benefits of adaptation options: A review of existing literature*, UNFCCC Technical Paper.

URS Corporation, 2010, *Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change* Ref. No RMP/5456.

Vafeidis, A.T., Nicholls, R.J., McFadden, L., Tol, R.S.J., Hinkel, J., Spencer, T., Grashoff, P.S., Boot, G., Klein, R., 2008, 'A new global coastal database for impact and vulnerability analysis to sea-level rise', *J Coast Res* (24) 917–924, doi:910.2112/2106-0725.2111.

van der Brugge, R., Rotmans, J. and Loorbach, D., 2005, 'The transition in Dutch water management', *Regional Environmental Change* (5) 164–176.

van Ierland E.C., de Bruin, K., Dellink, R.B. and Ruijs, A., 2006, *A qualitative assessment of climate change adaptation options and some estimates of adaptation costs. Routeplanner naar een klimaatbestendig Nederland Adaptatiestrategiën*. Study performed within the framework of the Netherlands Policy. Programme ARK as Routeplanner projects 3, 4 & 5.

van Vuuren, D.P. Edmonds, J.A,. Kainuma, M., Riahi, K., Weyant, J., 2011, 'A special issue on the RCPs', *Climatic Change* (109) 1–4.

van Vuuren, D. P., Riahi, K., Moss, R., Edmonds, J., Thomson, A., Nakicenovic, N., Kram, T., Berkhout, F., Swart, R., Janetos, A., Rose, S.K. and Arnell, N., 2012, 'A proposal for a new scenario framework to support research and assessment in different climate research communities', *Global Environmental Change-Human And Policy Dimensions* (22/1) 21–35.

von Ungern-Sternberg, T., 2004, *Efficient Monopolies. The Limits of Competition in the European Property Insurance Market*. Oxford University Press.

Walker, W.E., Rahman, S.A. and Cave, J., 2001, 'Adaptive Policies, Policy Analysis, and Policymaking', *European Journal of Operational Research* (128) 282–289.

Watkiss, P. (editor), 2011, *The ClimateCost Project. Final Report. Volume 1: Europe*. Published by the Stockholm Environment Institute, Sweden. ISBN 978-91-86125-35-6.

Watkiss, P. and Hunt, A., 2010, *Review of Adaptation Costs and Benefits Estimates in Europe for the European Environment State and Outlook Report 2010*. Technical Report prepared for the European Environmental Agency for the European Environment State and Outlook Report 2010, Copenhagen, Denmark. Published online by the European Environment Agency.

Watkiss, P. and Hunt, A., 2011, *Method for the UK Adaptation Economic Assessment (Economics of Climate Resilience)*. Final Report to Defra. Deliverable 2.2.1. Published by Department for Environment, Food and Rural Affrairs, London, the United Kingdom.

WEF, 2010, *Global Risks 2010. A Global Risk Network Report*. World Economic Forum.

Werners, S., Swart, R., van Slobbe, E., Bölscher, T., Pfenninger, S., Trombi, G. and Moriondo, M., 2012, *Turning Points In Climate Change Adaptation, The Governance of Adaptation — An international symposium*, Amsterdam, the Netherlands, http://www.adaptgov.com.

WHO, 2009, *Improving Public Health Responses to Extreme Weather/Heat-waves — EuroHEAT*, Technical Summary. WHO Regional Office for Europe, Copenhagen.

Willows R. and R. Connell, 2003, *Climate adaptation: Risk, uncertainty and decision-making*. UKCIP Technical Report.

Wilson, D., Renou-Wilson, F., Farrell, C., Bullock, C., Müller, C., 2012, *Carbon Restore –The Potential of Restored Irish Peatlands for Carbon Uptake and Storage — The Potential of Peatlands for Carbon Sequestration*. Climate Change Research Programme (CCRP) Report 15: http://www.epa.ie/downloads/pubs/research/climate/name,33710,en.html.

Winograd, M., 2009, 'QUICKScan: An emerging process and toolbox to support EEA/EU ecosystem assessments and decisions, Roundtable discussion of emerging ecosystem services tools and applications within corporate decision making', 13–14 October 2009, University of Vermont, Burlington, USA.

World Bank, 2010, *The Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates. The Global Report of the Economics of Adaptation to Climate Change Study*, http://siteresources.worldbank.org/INTCC/Resources/EACCReport0928Final.pdf.

WWF, 2010, *Assessment of the restoration potential along the Danube and main tributaries*, Final Draft, Vienna, WWF International, Danube-Carpathian Programme.

Yohe, G., 1990, *Imbedding dynamic responses with imperfect information into static portraits of the regional impact of climate change*. Presented at: International workshop on the natural resource and economic implications of global climate change, Interlaken, Switzerland.

European Environment Agency

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Addressing risks and opportunities from climate change
in the context of socio-economic developments

2013 — 132 pp. — 21 x 29.7 cm

ISBN 978-92-9213-385-6
doi:10.2800/50924

TH-AL-13-004-EN-C
doi:10.2800/50924

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ISBN 978-92-9213-385-6
9 789292 133856

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