Climate Change Impacts, Adaptation and Vulnerability in Scotland:

An integrated approach

Paula A. Harrison
and the CLIMSAVE consortium

Preface

The research reported here was undertaken as part of the CLIMSAVE project ("Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaptation and Vulnerability in Europe"). CLIMSAVE was conducted over the period January 2010 to October 2013 under the European Commission's Seventh Framework Programme (Contract number 244031). It was coordinated by Dr. Paula Harrison from the Environmental Change Institute at the University of Oxford and was implemented as a collaborative project by the following scientists and institutions:

- ⇨ Paula Harrison, Robert Dunford and Pam Berry, Environmental Change Institute, Oxford University Centre for the Environment, UK
- ⇨ George Cojocaru and Cristina-Mirela Savin, TIAMASG Foundation, Romania
- ⇨ Marc Gramberger, Martin Watson and Marjan Maes, Prospex bvba, Belgium
- ⇨ György Pataki, Chris High, Ágnes Kalóczkai and Gusztáv Nemes, ESSRG Kft, Hungary
- ⇨ Ian Holman and Eric Audsley, Cranfield University, UK
- ⇨ Santi Sabaté, Anabel Sanchez and Joan Maspons, CREAF, Spain
- ⇨ Karl-Heinz Simon, Florian Wimmer, Benjamin Stuch and Martina Flörke, University of Kassel, Germany
- ⇨ Mirek Trnka and Martin Dubrovsky, Mendel University, Czech Republic
- ⇨ Michalis Skourtos and Areti Kontigianni, University of the Aegean, Greece
- ⇨ Rob Tinch, Belgium
- ⇨ Ines Omann and Jill Jäger, SERI, Austria
- ⇨ Mark Rounsevell, Marc Metzger, Calum Brown and Evan Brown, University of Edinburgh, UK
- ⇨ Martin Sykes and Florian Sallaba, University of Lund, Sweden
- ⇨ Kasper Kok, Wageningen University, The Netherlands
- ⇨ Robert Nicholls, Abiy Kebede and Mustafa Mokrech, University of Southampton, UK
- ⇨ Lin Erda and Minpeng Chen, Institute of Environment and Sustainable Development in Agriculture, China
- ⇨ Richard Warrick, University of the Sunshine Coast, Australia
- ⇨ Roger Jones, Victoria University, Australia

The project was implemented at two scales: Europe and Scotland. This report summarises the policy relevant final results of the project for the Scottish case study. Three professionally facilitated workshops were organised in Scotland throughout the lifetime of CLIMSAVE to effectively integrate stakeholder views into the climate change impact and adaptation research. The workshops focused on the development of participatory scenarios which were integrated within a software tool (the CLIMSAVE Integrated Assessment Platform). The project team would like to acknowledge and thank all the stakeholders who provided their valuable input to these workshops.

Further information can be obtained from the project's website (www.climsave.eu) or by contacting the Project Coordinator: Dr. Paula Harrison (Paula.Harrison@ouce.ox.ac.uk).

Cover photo credit: Cornfield and forest (ClimateXChange); Coast (Iain Brown); River (SNIFFER/Adaptation Scotland).

Key findings

There is widespread acceptance that the climate is changing and, thus, it is vital that decision-makers have access to reliable science-based information to help them respond to climate change impacts and assess opportunities for adaptation. CLIMSAVE is a pan-European project that has developed an integrated assessment approach that enables stakeholders to explore and understand the cross-sectoral benefits and conflicts of different adaptation options to better inform the development of robust policy responses. The main findings for the Scottish case study were:

- ⇨ The CLIMSAVE Integrated Assessment (IA) Platform is a unique user-friendly, interactive web-based tool that enables Scottish stakeholders to explore the complex multi-sectoral issues surrounding impacts, adaptation and vulnerability to climate and socio-economic change across Scotland within the agriculture, forest,biodiversity,coast,water and urban sectors. See pages 6 and 7.

- ⇨ A range of climate change scenarios based on the UK Climate Projections are incorporated into the IA Platform to allow the User to explore the effects of climate change uncertainties on impacts and vulnerabilities. Projections of annual temperature change range from around +1 to +3^{o}C in the 2050s, whilst precipitation changes range from increases of between 2 and 24% in winter and from increases of 5% to decreases of 12% in summer. See pages 8 and 9.

- ⇨ Four contrasting socio-economic storylines were developed in a series of participatory workshops by Scottish stakeholders and quantified to include in the IA Platform. This led to strong feelings of ownership of the scenarios which illustrate that a broad range of futures are envisioned to be plausible for Scotland, ranging from the very positive (Mactopia) to the very negative (Mad Max). See pages 10 and 11.

- ⇨ Scotland will be significantly influenced by both climate and socio-economic change. Urban development increases in most scenarios. The number of people affected by a 1 in 100 year flood increases in the Highlands and Islands. Changes in biodiversity vulnerability, water exploitation and irrigation usage vary depending on the socio-economic scenario. Changes in land use (intensive farming, extensive farming, forests and unmanaged land) also vary depending on the scenario, with the exception of intensive farming in southern Scotland which shows general decreases. Food production only increases in the Highlands and Islands, whilst forest area decreases across Scotland. See pages 12 to 15.

- ⇨ The broad range of adaptation options to address the impacts of climate change in Scotland in the IA Platform allows the User to consider their costs, capital requirements, applicability, effectiveness and secondary (synergistic and cross-sectoral) impacts, but detailed assessment is needed to take account of local conditions and constraints. See pages 16 to 21.

- ⇨ However, effective adaptation emerging out of decisions made by local community actors needs to be strongly supported by an empowering national institutional setting. Support on adaptation in Scotland is becoming increasingly mainstreamed to deliver the new Scottish Climate Change Adaptation Programme by a broad stakeholder community. See pages 4 and 5.

- ⇨ Mapping of vulnerability hotspots suggest that human well-being may benefit from climate change with vulnerability reducing for warmer climate scenarios across a range of socio-economic scenarios. See pages 22 to 25.

- ⇨ The most robust policy strategy (defined in terms of beneficially reducing vulnerability to climate and socio-economic change across sectors, scenarios and spatial scales) is one that increases coping capacity through an increase in social and human capital. See pages 26 to 29.

- ⇨ A review of adaptation and mitigation measures showed that almost all had impacts beyond the original intended one, often in a different sector(s) and many of these were cross-sectoral interactions. Those between adaptation and mitigation measures were positive, representing potentially cost-effective synergies for addressing climate change. See pages 30 and 31.

How can policy promote climate change adaptation?

Scotland has taken early and concerted action to adapt to climate change. The Climate Change Act (Scotland), which was passed in 2009, requires the Scottish Government to establish an adaptation programme, creates duties upon public bodies to deliver this programme, and sets out a reporting infrastructure to measure progress. The Climate Change Act (Scotland) has also established the basis for a sustainable land use strategy aimed at achieving a more integrated approach to land use planning which maintains the future capacity of Scotland's land.

A Scottish Climate Change Adaptation Framework was published in 2009, with the intention of catalysing improvements with respect to adaptation and resilience (Figure 1). The UK Climate Change Risk Assessment (CCRA), which was called for by the UK Climate Change Act 2008 and was partly funded by the Scottish Government, also produced a report in 2012 on climate change risks in Scotland. The Climate Change Act (Scotland) requires the Scottish Government to draw up an Adaptation Programme to address the identified risks within this assessment. The Scottish Climate Change Adaptation Programme (SCCAP) is currently undergoing public consultation (www.scotland.gov.uk/Resource/0042/00426529.pdf) and will be published in late 2013.

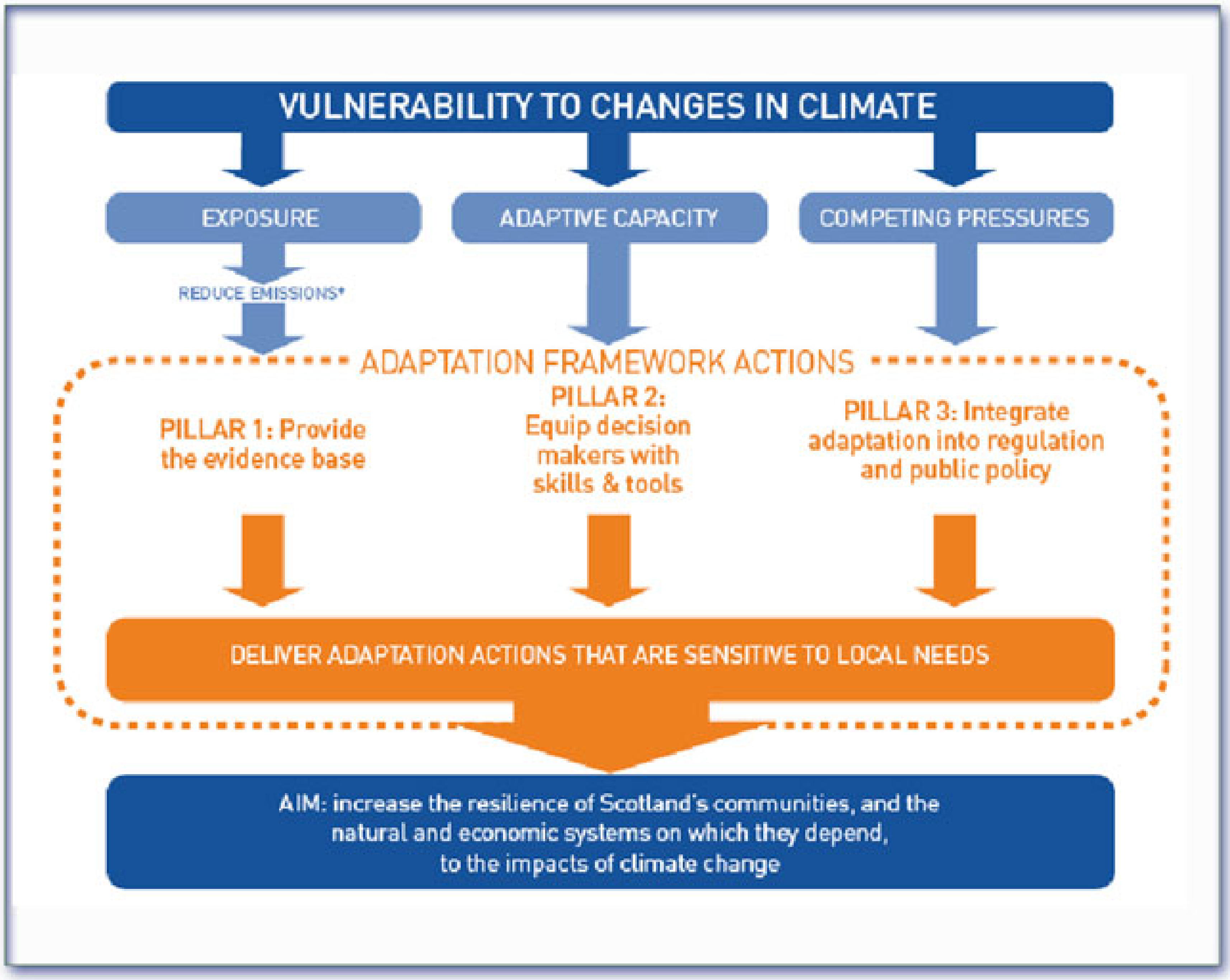


Figure 1: Scotland's Climate Change Adaptation Framework. Source: www.scotland.gov.uk/Publications/2009/12/08130513/5.

In order to make the Scottish Climate Change Adaptation Framework operational, 12 sectoral action plans were developed with a common structure, including an analysis of potential impacts, and policies and drivers for the sector. Emphasis is put upon understanding the consequences of a changing climate and, then, equipping decision-makers with skills and tools in order to be able to integrate adaptation into public policy and regulation.

Institutionally, Scotland benefits from a strong governance culture and the dense networks of relationships between government and other policy actors possible within a smaller polity. At the UK level of governance, there are mechanisms such as the climate change concordat which describe how policy should be coordinated. In particular, the Committee on Climate Change and its subsidiary the Adaptation Sub-Committee (ASC) provide independent advice to the UK government and the devolved administrations on climate change. The ASC has developed a "preparedness ladder" which characterises adaptation in terms of outcomes, driven by actions and decisions. It has been used to develop an initial set of indicators to track trends in realised impacts, components of vulnerability and the uptake of adaptation actions.

Much Scottish policy is delivered by public bodies; organisations which are operationally independent from the government, but which report to it and receive much of their funding from it. There are a range of public bodies with an interest in adaptation, which not only deliver policy under the duties imposed on them by central government, but also play an active role in shaping policy. A key programme with responsibility for influencing action by public and private actors with respect to climate change is Adaptation Scotland (www.adaptationscotland.org.uk). This is funded by the Scottish Government and delivered by Sniffer; a registered charity that delivers knowledge-based solutions to resilience and sustainability issues in Scotland. Furthermore, the Scottish Government has recently funded ClimateXChange (www.climatexchange.org.uk), a collaborative initiative between sixteen of Scotland's leading research and higher education institutions to deliver objective, independent, integrated and authoritative evidence to support the Government in relation to its activities on climate change mitigation, adaptation and the transition to a low carbon economy.

A key approach to policy in Scotland is iteration, with a cycle of consultation, formulation, implementation and review; often on a five year cycle. This creates opportunities for policy integration ('climate mainstreaming') because as new policies are introduced they influence the updating of existing strategies. Support on adaptation is also becoming increasingly mainstreamed, in particular as the Public Bodies Duties come into force, which include an obligation to act in the way best calculated to deliver the Scottish Climate Change Adaptation Programme. This obligation builds on a longstanding commitment by Scottish local authorities to report on their adaptation actions on an annual basis. Support is provided to help organisations understand how they can meet their obligations, reflecting a maturation of the adaptation agenda in Scotland and thereby ensuring that adaptation plans are put into practice.

How can stakeholders explore climate change impacts and opportunities for adaptation?

Decision-makers and other interested Scottish citizens need to be able to access reliable science-based information to help them respond to the risks of climate change impacts and assess opportunities for adaptation.

The CLIMSAVE Integrated Assessment (IA) Platform is a unique, interactive, exploratory web-based tool to allow Scottish stakeholders to assess for themselves climate change impacts and vulnerabilities for a range of sectors (Figure 2). It provides rapid user-friendly interactivity through www.climsave.eu and the European Climate Adaptation Platform (CLIMATE-ADAPT - http://climate-adapt.eea.europa.eu/), helping to broaden accessibility and participation and increase impact in research communities.

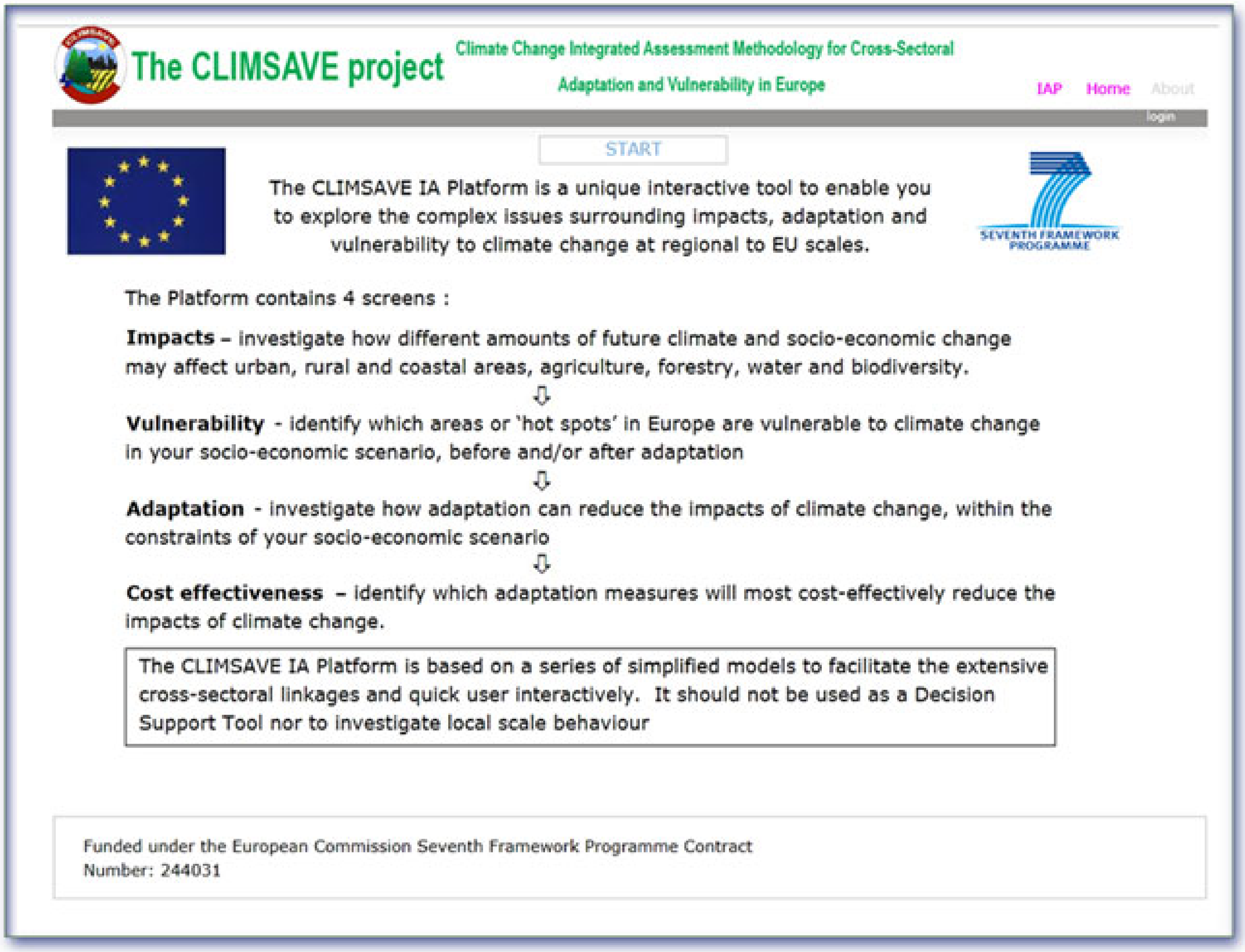


Figure 2: Introductory screen to the CLIMSAVE IA Platform

The CLIMSAVE IA Platform screens

The CLIMSAVE IA Platform is designed to facilitate a two-way iterative process of dialogue and exploration of "what if's" through its different screens:

- ⇨ **Impacts screen** – investigate how different amounts of future climate and socio-economic change may affect urban, rural and coastal areas, agriculture, forestry, water and biodiversity in Scotland (Figure 3).

- ⇨ **Vulnerability screen** – identify which areas or 'hot spots' in Scotland are vulnerable to climate change in your selected climate and socio-economic scenarios, before and/or after adaptation (Figure 4). Vulnerable regions are those in which impacts before or after adaptation are high and the coping capacity of society is low.

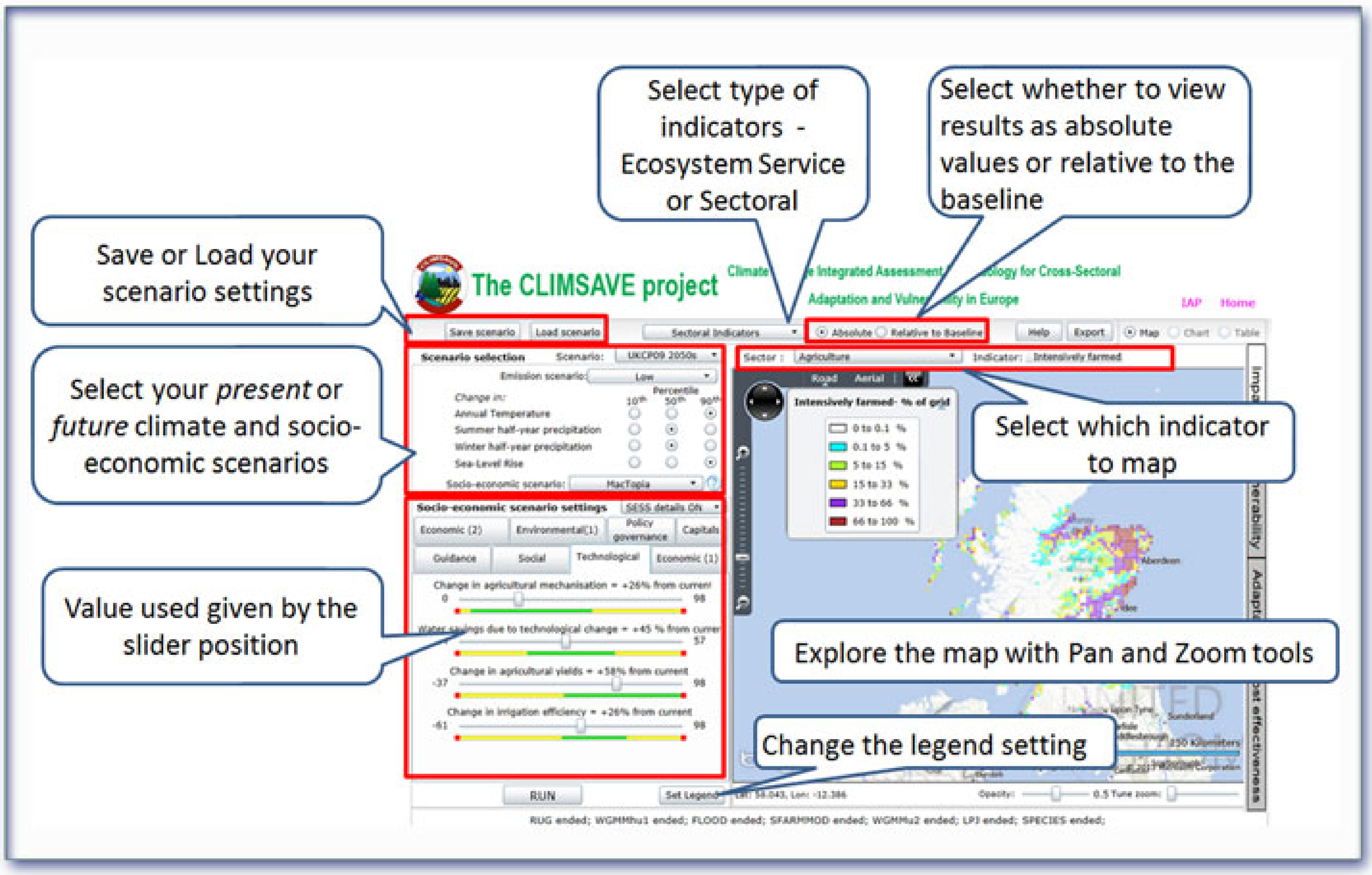


Figure 3: The Impacts screen of the Scottish IA Platform

⇨ **Adaptation screen** – investigate how adaptation can reduce the impacts of climate change in Scotland, within the constraints of your socio-economic scenario. These include scenario-independent limits (technical, physical, etc), scenario-specific values and scenario-specific resource availability.

⇨ **Cost-effectiveness screen** – as each slider or button on the Adaptation screen represents the combined effects of multiple individual adaptation measures, this screen allows you to investigate the relative cost-effectiveness of these different adaptation measures.

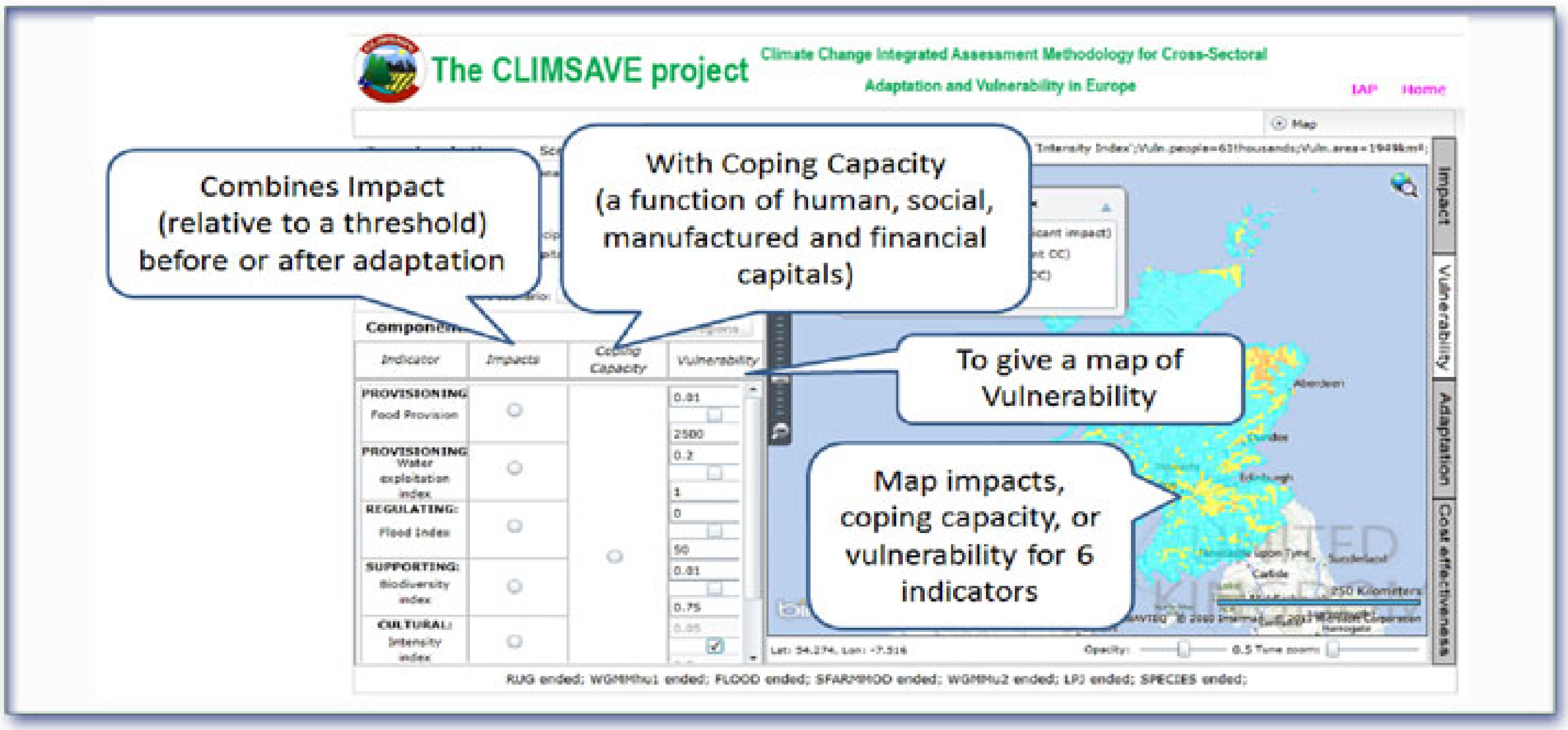


Figure 4: The Vulnerability screen of the Scottish IA Platform

The power of the CLIMSAVE IA Platform lies in its holistic framework (cross-sectoral, climate and socio-economic change) that is intended to complement, rather than replace, the use of more detailed sectoral tools in informing the development of robust policy responses.

What are plausible futures for Scotland?

Scenarios help us to understand the different ways in which the future might develop and can be utilised to evaluate and change current thinking and, thus, improve decision-making. Scenarios can also be used, as has been done in CLIMSAVE, to integrate knowledge and enhance 'out of the box' thinking across expertise (stakeholders and researchers), disciplines (areas of expertise), and a wider range of factors, sectors and actors. Two types of scenarios have been developed: climate change scenarios and socio-economic scenarios.

Climate change scenarios

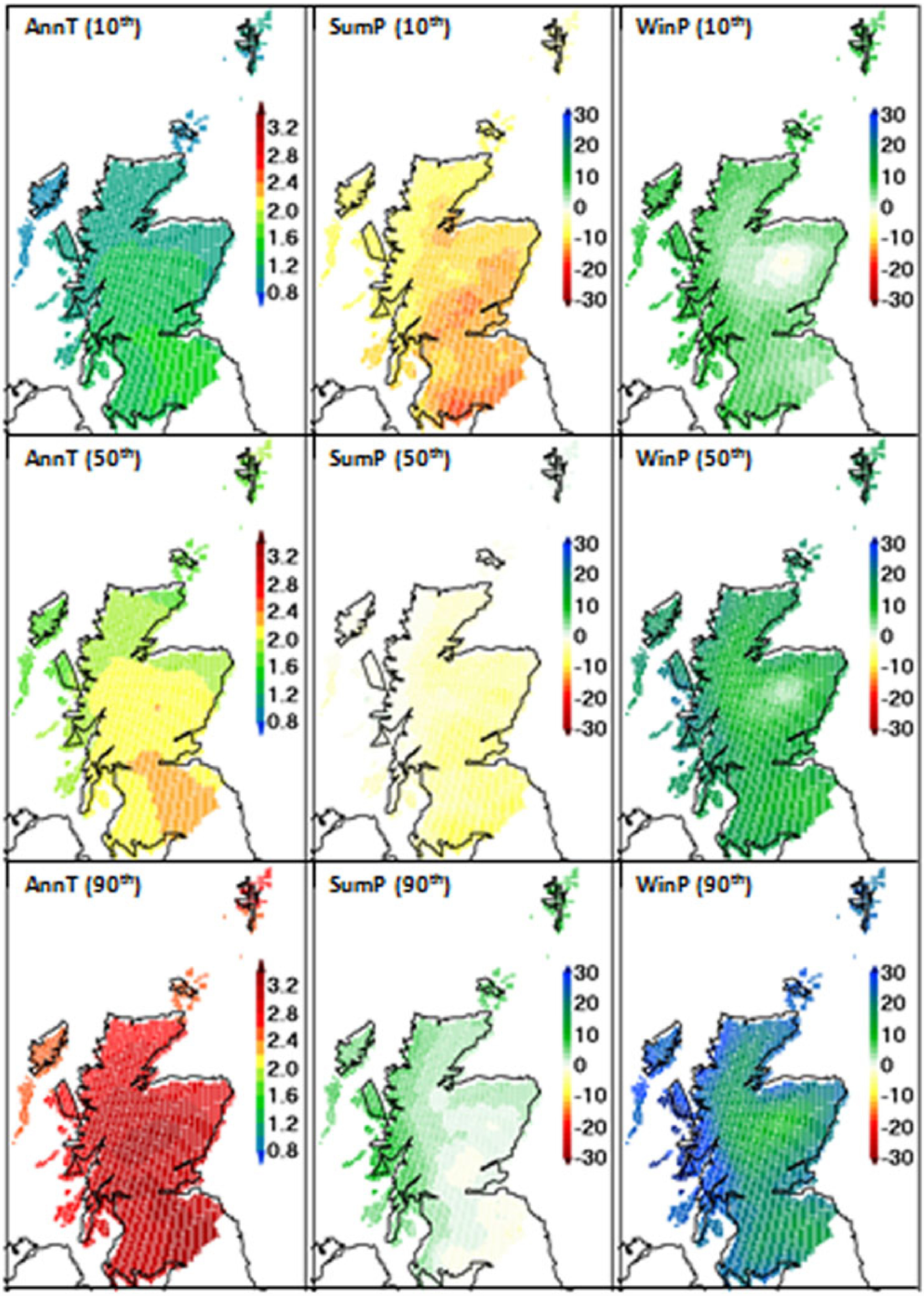
A range of climate change scenarios were prepared and incorporated within the IA Platform, based on the UK Climate Projections 2009 (UKCP09). The user interface to the Scottish IA Platform allows the user to select a greenhouse gas emissions scenario (Low, Medium and High, equivalent to the SRES B1, A1B and A1F1, respectively), and the associated amount of climate change in order to explore the effects of climate change uncertainties on impacts and vulnerabilities. UKCP09 scenarios are different to those used in the European IA Platform as they assign probabilities (or likelihoods) to the projections of temperature and precipitation change, based on the results of 10,000 climate model simulations per emissions scenario. In order to make the number of combinations manageable for the user, it was decided to identify different degrees of climate change from within these many model simulations. Thus, a methodology was developed to objectively calculate low, medium and high degrees of future warming within a given emissions scenario (based on the 10th, 50th and 90th percentiles of the future average annual temperature) and their associated 10th, 50th and 90th percentiles (representing dry, typical and wet) of the average summer half year (April to September) and winter half year (October to March) precipitation change.

Projections of Scotland-wide area-average temperature and precipitation change are shown in Table 1. Patterns of temperature and precipitation change for the medium emissions scenario and the three percentiles are shown in Figure 5.

Table 1: Scotland area-average changes in annual temperature and summer- and winter-half year precipitation for the 2050s, for the three percentiles of temperature change and associated precipitation change percentiles for the UKCP09 emissions scenarios.

Emissions	Annual temperature change percentile	Annual temperature change (°C)	Summer half-year precipitation change (%)			Winter half-year precipitation change (%)		
			10th	50th	90th	10th	50th	90th
Low	10th	1.1	-8.6	-1.7	5.4	1.6	8.0	15.0
	50th	1.8	-9.8	-2.7	4.7	2.5	9.2	16.3
	90th	2.7	-11.4	-3.9	3.9	3.8	10.9	18.6
Medium	10th	1.2	-10.2	-3.5	3.3	5.0	11.9	19.1
	50th	2.0	-11.0	-4.0	3.0	6.1	13.2	20.6
	90th	3.0	-12.0	-4.8	2.9	7.8	15.5	23.6
High	10th	1.4	-9.2	-2.3	4.8	4.9	12.3	20.3
	50th	2.2	-10.5	-3.4	4.1	5.7	13.4	21.7
	90th	3.3	-12.0	-4.3	3.6	7.0	15.4	24.3

Figure 5: Annual temperature change (AnnT, ^{o}C), summer half-year precipitation change (SumP, %) and winter half-year precipitation change (WinP, %) for the 10th, 50th and 90th percentile projections for all variables under the UKCP09 medium emissions scenario.



Socio-economic scenarios

Climate change impacts will be in addition to, or concurrent with, those associated with continuing socio-economic and political changes. Our vulnerability to climate change, therefore, needs to be evaluated in a holistic or integrated assessment of the effects of our changing future. A set of plausible socio-economic futures for Scotland were developed with stakeholders through a series of workshops (Figure 6). This participatory approach has two main advantages. Firstly, by developing qualitative scenarios in the form of stories it is relatively easy for a broad range of stakeholders from different backgrounds, expertise and professions to participate. Additionally, the stories are a good basis to stimulate discussion and ultimately shared learning. Secondly, stakeholders quantify the resulting stories, which serve as an important input for the CLIMSAVE IA Platform. In this way, the perspectives of stakeholders on future developments in a number of key sectors, such as agriculture, water, forests and biodiversity can be integrated with model outputs, leading to a set of qualitative and quantitative scenarios co-produced by stakeholders and CLIMSAVE experts.

The CLIMSAVE project developed these scenarios through three professionally facilitated, participatory workshops, which were very positively evaluated by stakeholders. In addition to the development of long-term scenarios of socio-economic change, adaptation options for reducing climate change vulnerability were appraised.

Figure 6: Photo from the 2nd Scottish stakeholder workshop held in Edinburgh in February 2012.

The scenarios were developed by looking at forces that drive changes within society and the environment we live in, including changes in social, economic and institutional factors. Stakeholders participating in the workshops drafted a list of the main uncertainties facing Scotland and from this list selected two key uncertainties that formed the basis for four scenarios (Figure 7). The two key uncertainties were whether well-being and lifestyle would be equitably or disparately distributed throughout society and whether resources would be in surplus or deficit.

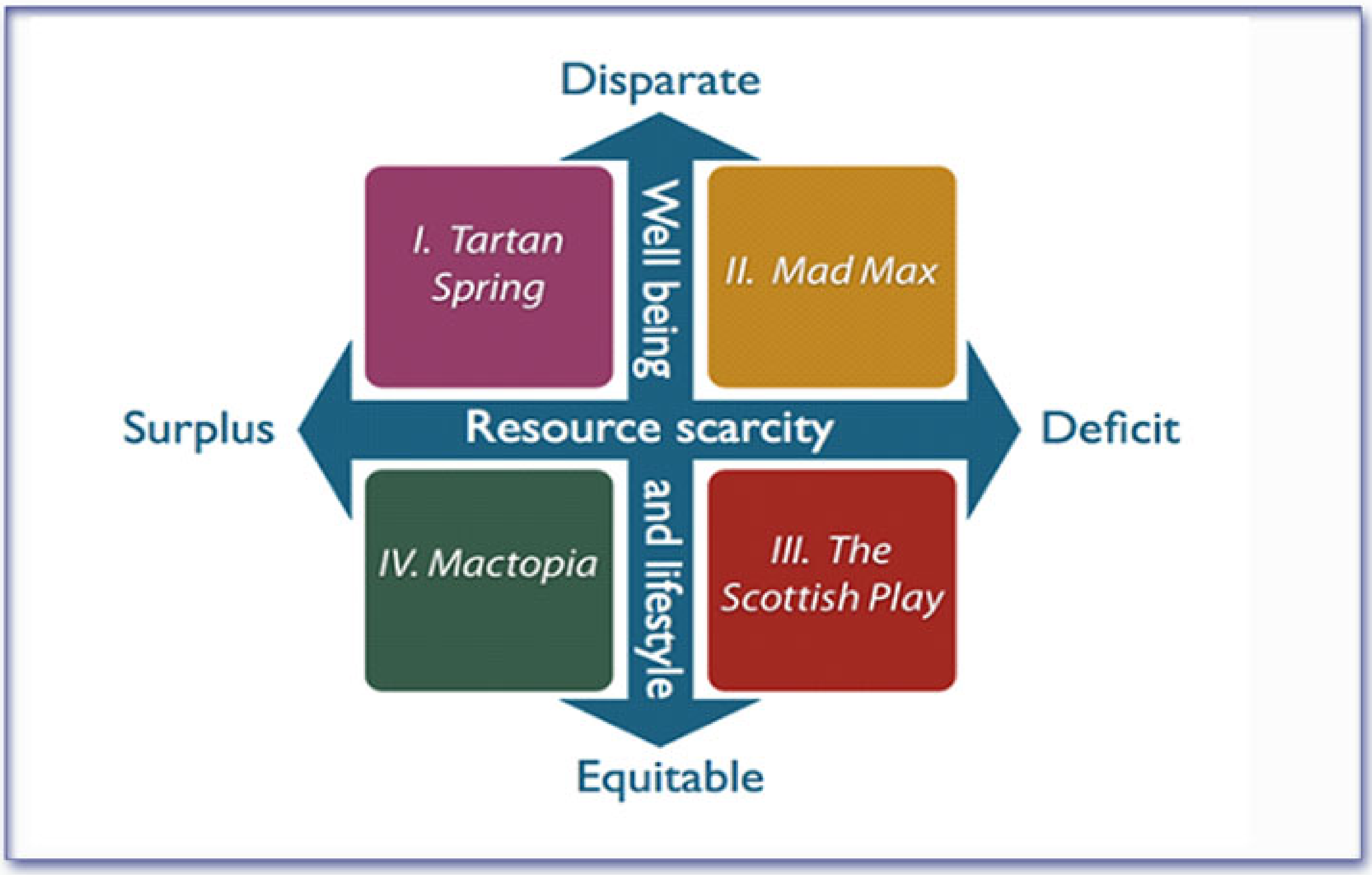


Figure 7: Structure and names of the four CLIMSAVE socio-economic scenarios for Scotland.

Within the Tartan Spring scenario a far-reaching, poorly regulated privatisation, changes Scotland from a prosperous country with abundant resources to one with an eroded social fabric and a low standard of living, culminating in an uprising.

Equally driven by crises a new self-centred paradigm emerges in the Mad Max scenario, which leads to a growing disparity in society. Survival from day-to-day prevails, while new 'clans' are ruling Scotland again.

Although resources within The Scottish Play scenario are equally scarce, the scenario can rely on traditional Scottish values to deal with the lack of resources. Consequently, lifestyles change towards reducing, re-using, and recycling, leading to a poorer, but greener and, in a way, happier population.

In the most fortunate scenario, Mactopia, a resource surplus helps Scotland to make a transition towards an equitable and sustainable society to eventually become an IT, life sciences, green technology and finance frontrunner led by a powerful middle class.

The CLIMSAVE socio-economic scenarios illustrate that a broad range of futures are envisioned to be plausible for Scotland, ranging from the very positive (Mactopia) to the very negative (Mad Max or Tartan Spring).

What are the key impacts of climate change?

Numerous studies have explored the impacts of climate change at a variety of spatial scales in Scotland and the United Kingdom. However, most of these treat each sector independently thereby ignoring important feedbacks and cross-sectoral interactions. Cross-sectoral interactions are important since changes in one sector can affect another sector either directly, e.g. changes in land use affect regional hydrology or biodiversity, or indirectly through policy, e.g. measures designed for coastal flood defence also impact on coastal habitat. Ignoring cross-sectoral interactions can lead to either over- or under-estimation of climate change impacts and the need for adaptation. Furthermore, many previous studies report the impacts of climate change under current socio-economic conditions, but in fact impacts will interact with those associated with continuing socio-economic and political changes, in potentially complex, non-additive ways.

The CLIMSAVE IA Platform was run for 30 climate change and socio-economic change scenarios for the 2050s timeslice to explore the effects of climate change uncertainties on cross-sectoral impacts. The scenario combinations can be categorised into two groups:

- ⇨ Climate scenarios across the range of UK Climate Projections incorporated within the IA Platform (see pages 8-9) from the 10th percentile annual temperature increase associated with low emissions (and the associated range of changes in precipitation) to the 90th percentile annual temperature increase associated with high emissions (6 runs);
- ⇨ Climate scenarios (the 6 runs above) combined with the four CLIMSAVE socio-economic scenarios (see pages 10-11; 24 runs).

Each scenario run was analysed for thirteen indicators representing the six sectors considered within CLIMSAVE (agriculture, forestry, biodiversity, water, coasts and urban). The indicators were analysed for the whole of Scotland and four catchment-based regions for southern, central and north eastern Scotland, and the Highlands and Islands.

Uncertainty in future impacts due to climate scenarios

The effects of uncertainty due to the climate change scenarios (assuming baseline socio-economics) are shown in Table 2. This shows the minimum and maximum area-average values across the 6 climate change scenarios for each indicator and region. Most indicators are expressed as percentage change from the baseline, except for the Biodiversity Vulnerability Index and Intensity Index (where the indices are already calculated relative to the baseline) and irrigation usage and forest area which are given as absolute changes. The results show that there is a good degree of confidence in the direction of change for most indicators at the national scale, with only water availability, water exploitation index and unmanaged land showing uncertainty in the direction of change nationally. There is, however, considerable uncertainty in the direction of change for many of the indicators at the regional scale. The robust results are that:

- ⇨ There is no change in **artificial surfaces** as climatic factors do not influence urban development.
- ⇨ The number of **people flooded** in a 1 in 100 year event increases in all regions. Regional changes are modest, but are locally significant given the sparse population over wide areas of Scotland. The increases reflect the impact of the relatively moderate increases in sea-level by the 2050s (8-36 cm) under the climate change scenarios on coastal towns and cities. Furthermore, at the resolution of the Scottish grid cell, fluvial flooding doesn't significantly increase the number of people flooded in the absence of socio-economic changes.

⇨ **Biodiversity vulnerability** decreases in all regions of Scotland. The index is based on a group of 11 species selected to represent a cross-section of Scottish species from different taxa, regions and habitats. Their vulnerability increases when the climate becomes less suitable. The reduction in vulnerability in Scotland reflects many of the selected species gaining climate space in the northeast and Highlands and Islands as the climate becomes warmer and sometimes wetter.

Table 2: Minimum and maximum values of the mean change from baseline for the 2050s for the climate change scenarios combined with baseline socio-economics. Coloured cells show indicators where the minimum and maximum trends are in different directions; where this is not the case the direction of the trend may be seen as robust in the context of the scenarios.

Indicator	Scotland		Highlands and Islands		Southern		Central		North-east	
	Min	Mix	Min	Max	Min	Max	Min	Max	Min	Max
Artificial surfaces (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
People flooded (%)	10.7	31.6	21.8	47.6	1.2	9.4	7.3	29.9	0.0	13.2
Biodiversity VI (-)	-0.40	-0.20	-0.40	-0.10	-0.30	-0.10	-0.30	0.0	-0.50	-0.30
Intensively farmed (%)	12.2	51.1	38.9	74.9	-60.0	19.1	-35.4	65.5	37.0	85.9
Extensively farmed (%)	6.1	37.1	-4.5	18.0	20.7	89.6	-7.1	87.3	-32.1	30.5
Food production (%)	28.7	130.7	78.5	178.1	-42.4	107.0	-36.8	119.7	36.3	130.2
Forest area (km²)	-50.5	-37.1	-58.4	-32.7	-38.2	-27.0	-50.3	-24.4	-62.2	-36.8
Unmanaged land (%)	-0.3	0.4	-0.3	0.3	0.0	0.1	-0.2	1.4	-0.2	1.4
Intensity index (-)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Land use diversity (%)	0.0	47.0	0.0	12.0	0.0	78.0	0.0	139.0	0.0	63.0
Water availability (%)	-4.5	15.8	-4.2	19.1	-7.2	9.3	-6.1	13.4	-7.0	9.6
Water Exploitation Index (%)	-8.4	23.4	-12.5	19.5	-7.9	68.0	-7.7	19.7	-7.5	30.6
Irrigation usage (10^3 m³/yr)	6.1	17.8	5.7	14.1	-6.6	12.9	0.5	15.9	13.9	39.3

Table 3: Minimum and maximum values of the mean change from baseline for the 2050s for the climate change scenarios combined with the CLIMSAVE socio-economic scenarios. Coloured cells show indicators where the minimum and maximum trends are in different directions; where this is not the case the direction of the trend may be seen as robust in the context of the scenarios.

Indicator	Scotland		Highlands and Islands		Southern		Central		North-east	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Artificial surfaces (%)	0.0	31.7	0.0	19.1	0.0	70.2	0.0	27.8	0.0	45.4
People flooded (%)	-2.3	63.3	7.6	72.4	-11.8	71.8	-4.5	55.9	-15.1	67.9
Biodiversity VI (-)	-0.30	0.00	-0.30	-0.10	-0.20	0.00	-0.20	0.10	-0.40	0.00
Intensively farmed (%)	-54.4	46.1	-37.7	93.9	-93.5	-30.8	-81.5	38.3	-64.9	74.4
Extensively farmed (%)	-60.6	62.7	-50.7	32.4	-60.6	108.3	-91.2	127.6	-64.8	99.9
Food production (%)	-9.7	93.2	25.0	252.4	-83.6	21.9	-76.7	42.5	-31.2	141.3
Forest area (km²)	-55.0	-9.4	-70.5	-15.3	-54.1	-3.6	-71.0	-2.1	-46.4	-1.4
Unmanaged land (%)	-0.4	51.9	-0.4	25.8	-0.3	227.3	-1.5	242.5	-0.4	93.8
Intensity index (-)	-0.1	0.0	-0.1	0.0	-0.2	0.0	-0.1	0.1	-0.2	0.1
Land use diversity (%)	0.0	223.0	0.0	58.0	0.0	395.0	2.0	601.0	0.0	319.0
Water availability (%)	-4.5	15.8	-4.2	19.1	-7.2	9.3	-6.1	13.4	-7.0	9.6
Water Exploitation Index (%)	-57.7	57.5	-61.9	34.5	-57.6	278.5	-57.7	54.6	-52.2	110.6
Irrigation usage (10^3 m³/yr)	-21.3	10.9	-28.3	9.0	-18.7	8.4	-15.4	14.1	-7.0	27.2

⇨ **Land use indicators: Intensive farming** increases in the northeast and Highlands and Islands, leading to an overall national increase. **Extensive farming** increases in southern Scotland. **Food production** increases in the northeast and Highlands and Islands. **Forest area** decreases across all regions of Scotland. **Unmanaged land** shows little change in any region. The land use model's primary challenge is to ensure that enough food is supplied to support the Scottish population, allowing for food imports. This focus on food provision has the knock-on impact that, even in the absence of socio-economic scenarios, forest area declines often to be replaced by intensive or extensive agriculture.

⇨ The **land use summary indicators** reflect changes in land use with the **intensity index** showing no change or an increase across all regions of Scotland. **Land use diversity** remains unchanged or increases nationally and in all regions representing an increase in the homogeneity of the landscape. The reduction in the multi-functionality of the landscape is expected to reduce the robustness to the loss of the ecosystem services associated with any one land use.

⇨ **Water-related indicators: Irrigation usage** increases in all regions, but southern Scotland; most notably in northeast Scotland.

Uncertainty in future impacts due to climate and socio-economic scenarios

To evaluate the importance of future socio-economic change to the impact range associated with climate change uncertainty, Table 3 shows the minimum and maximum area-average change for each indicator and region when the climate change scenarios are combined with the CLIMSAVE socio-economic scenarios. The results show that there is increasing uncertainty in the direction of change at both the national and regional scales. The results show:

⇨ The socio-economic scenarios generally encourage **artificial surfaces** to increase. The model is heavily driven by population and GDP changes. Therefore, socio-economic scenarios with high population increase and higher GDP, such as Mactopia and Tartan Spring, see the most growth. Mad Max has a population decline and as such shows no growth.

⇨ The number of **people flooded** in a 1 in 100 year event increases in the Highlands and Islands, but the range is greater than seen for the climate scenarios alone. There is no clear trend for southern, central or north-eastern Scotland. This indicator is largely driven by population and changes in the distribution of the urban area.

⇨ The socio-economic scenarios partially offset the beneficial changes in the **biodiversity vulnerability index** driven by climate. This reflects changes in habitat availability driven by a range of socio-economic factors which affect land use change.

⇨ Land use indicators: The socio-economic scenarios make a significant difference to the patterns of **intensive and extensive farming** and **unmanaged land**: there is no longer a clear message for any region of Scotland with the exception of intensive farming in southern Scotland which shows general decreases. **Food production** only increases in the Highlands and Islands, whilst **forest area** decreases across Scotland; the socio-economic scenarios considerably increase the range of possible outcomes at national and regional scales. In scenarios such as The Scottish Play, where pressure is put on the food resource due to increasing population and a lack of resources there are significant increases in overall food production and extensive farming, and little change in intensive farming and unmanaged land, whilst the area of forestry declines greatly. Conversely in scenarios where innovations are successful and high GDP growth allows increased food imports (Mactopia), the area of unmanaged land increases at the expense of both intensive and extensive farming.

⇨ Land use summary indicators: The socio-economic scenarios heavily influence the land use **intensity index** and **land use diversity**. The intensity index decreases in Mactopia in all regions and generally increases under the remaining scenarios in all regions except southern Scotland. The changing patterns in land use also lead to impacts on land use diversity – all regions decrease in diversity due to loss of forest and changes to unmanaged and agricultural land.

⇨ **Water-related indicators**: There is no socio-economic influence on **water availability**. The socio-economic scenarios exacerbate the uncertainty in the direction of change in the **water exploitation index** and **irrigation usage** driven by climate alone in all regions, reflecting changes in both climate and socio-economic factors driving water extraction for agriculture, domestic/industrial use and power generation. In scenarios where societal breakdown and reducing wealth and resources lead to a loss of human and social capital (Mad Max), water consumption is higher leading to increased water exploitation index (greater stress) and irrigation use is considerably lower in most regions. Conversely the scenarios where human capital increases, enabling successful water-saving innovations or 'living with less' (Mactopia and The Scottish Play) use increasing amounts of irrigation, whilst maintaining lower water exploitation values in comparison to the impacts based on climate change alone.

Reflection

The outputs for each of the thirteen modelled indicators for each of the 30 scenario combinations were tested for significant differences compared to the modelled baseline. Between 65% and 97% of indicator-scenario combinations were found to be statistically significantly different from the baseline for Scotland and the four regions. These results clearly show that Scotland will be significantly influenced by future change. The results also show that non-climatic pressures, such as future socio-economic change, may be at least as, if not more, important than climate change, but there are many compounding and interacting effects (Figure 8). This highlights the importance of quantifying future impacts for both climate and socio-economic change to more fully capture uncertainties which can better inform the assessment of robust adaptation options.

Figure 8: Cross-sectoral summary of changes in the 25th and 75th percentiles of distributions for Scotland and four regions for the 2050s. 2050s BL is based on climate-only scenarios with baseline socio-economics. 2050s Mactopia and 2050s Mad Max are based on combined climate and socio-economic scenarios. Regions are Scot: Scotland; H&I: Highlands and Islands; S: southern Scotland; C: central Scotland; and NE: northeast Scotland.

	2050s BL					2050s Mactopia					2050s Mad Max				
	Scot	H&I	S	C	NE	Scot	H&I	S	C	NE	Scot	H&I	S	C	NE
Artificial surfaces (%)	•	•	•	•	•	•	•	•	↑	↑	•	•	•	•	•
People flooded (1000s people)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Water Exploitation Index (-)	>	•	↑	↕	+	↓	↓	-	↓	-	+	↑	↑	+	↑
Irrigation usage (m^3/yr)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Biodiversity VI (-)	↓	↓	-	-	↓	-	-	-	+	-	-	-	-	-	-
Food production (cal/day)	↑	↑	>	↑	↑	↕	↕	↓	↓	-	↑	↑	>	>	↑
Intensively farmed (%)	+	+	↓	↑	↑	•	•	↓	↓	↓	•	+	↓	↓	-
Extensively farmed (%)	+	+	+	↑	-	-	-	-	-	+	+	+	↑	↑	↑
Forest area (km^2)	-	↓	-	↓	↓	-	-	-	↓	-	-	-	-	↓	-
Unmanaged land (%)	•	•	•	•	•	↑	+	↑	↑	+	•	•	•	•	•
Intensity index (-)	•	•	•	+	+	-	•	-	-	-	•	•	•	•	•

↑	Increase >50% in either the 25th or 75th percentile with a non-negative change in the other
+	Increase >5% in either the 25th or 75th percentile with a non-negative change in the other
•	Change < ±5% in both the 25th or 75th percentile
-	Increase >5% in either the 25th or 75th percentile with a non-positive change in the other
↓	Decrease >50% in either the 25th or 75th percentile with a non-positive change in the other
>	Decrease > 5% in 75th percentile and Increase > 5% in 25th percentile – contracting distribution
↕	Increase > 5% in 75th percentile and decrease > 5% in 25th percentile – widening distribution

How might Scotland adapt to climate change?

Adaptation can be achieved through 'hard' options and 'soft' options. Hard options are engineering and technological solutions; soft options seek to change knowledge or behaviour (and can include changing information and incentives relating to adoption of hard options). Adaptation can be anticipatory or reactive, planned or autonomous. Anticipatory or proactive adaptation takes place before impacts of climate change are observed. Reactive adaptation takes place after the impacts of climate change have been observed. Behavioural changes taken by private actors as a reaction to actual or expected climate change are known as "autonomous" adaptation. Planned adaptation is the result of a deliberate policy decision based on an awareness that conditions have changed and that action is required to return to, maintain, or achieve a desired state. This is partly a matter of perspective: adaptation that is 'planned' by an individual farmer may be viewed as 'autonomous' by the ministry of agriculture (when farmers just get on and do it without any ministry intervention).

Within CLIMSAVE, autonomous adaptation, both anticipatory and reactive, occurs within the meta-models which run inside the IA Platform: for example, the agriculture model automatically selects the best crops for the climate and economic conditions. Planned adaptation is implemented by the Platform user changing the sliders or buttons that control the models – for example, changing the rate at which agricultural technology improves. Each of the sliders represent broad adaptation responses, which could be made up of a range of specific adaptation options, individually or in combination, in most cases including both hard options and soft options. Which options could actually be used is a matter of choice, and depends on the scenario and resources (capitals) available: for example, high wealth scenarios are well suited to expensive solutions; scenarios with strong government are well suited to regulatory and tax solutions; and so on. The cost-effectiveness screen seeks to aid Platform users in thinking about these choices, highlighting the costs, effectiveness, and capital requirements of the different options available for influencing a slider (see pages 20-21).

CLIMSAVE does not seek to cover all adaptation options, partly because it does not cover all sectors (so there are options in, for example, transport, health and industry that are not included) and partly because the sliders that control the models in the Platform do not reflect every possible aspect of the sectors modelled. Nevertheless, the sliders do cover a very wide range of possible options, and in particular for sectors with a strong influence on land use and land cover.

These adaptation options were identified in three main ways. Firstly, research into cost-effectiveness involved a wide-ranging search for estimates of the actual costs of adaptation options, resulting in an extensive database of (primarily hard) adaptation options (see pages 20-21). Secondly, work on adaptation and mitigation synergies and their cross-sectoral impacts involved a broader search (i.e. without the focus on costed options) for information on adaptation options (see pages 30-31). And finally, a range of additional ideas for future adaptation options, including many soft options, were developed in the CLIMSAVE stakeholder workshops, focusing on the sets of adaptation options that might be appropriate under the different future socio-economic scenarios developed by the stakeholders (see pages 10-11).

Agricultural sector

The agricultural sector has a capacity for autonomous adaptation through crop choices and changing practices, including the timing of crop operations, water management and changes in tillage. These can be encouraged by soft options, such as support and extension programmes to help farmers make the best choices. Hard/technological options include investments in conventional or GM crop breeding, better irrigation systems, increased mechanisation and precision farming methods. Different uses of fertilizers, nitrification inhibitors and so on can influence both yields and the environmental impact of farming. At a

societal level, changes in diet, for example, discouraging meat consumption could reduce pressure on agricultural systems. Expanding into marginal land could increase output, but could also have serious consequences for other sectors, notably biodiversity but also water and perhaps forestry and flooding. Increasing food imports could reduce domestic pressures, but could make people more vulnerable by making food supply more dependent on environmental and political conditions in foreign states.

Forestry sector

Like agriculture, there is a degree of autonomous adaptation in the forestry sector as private foresters will consider climate factors when making choices about tree species and forest management. However, the time lags in forestry are particularly large and this places a strong emphasis on outreach and information programmes to help foresters take the best long-term projections into account. Adaptation options to ensure timber demand is met include planting drought-resistant species, measures to reduce fire risks, and afforestation/reforestation of new areas. Cross-sectoral effects may be variable: newly wooded land could reduce land for agriculture and nature conservation, but could also benefit biodiversity. Water supplies may be cleaner and released in a more controlled fashion, with flood risks reduced, but water quantities can also be reduced due to increased interception by tree canopies. This is unlikely to be a problem in relatively wet, low population areas such as Scotland.

Water sector

Adaptation options in the water sector include various 'hard' options for improving water storage, such as dam construction, desalination, aquifer recharge and even using renewable energy to extract water from the atmosphere. Many of these options are large-scale, but smaller scale equivalents exist and could be encouraged using soft options such as information programmes or subsidies for investments. Behavioural change could also be important for adaptation in the water sector; encouraging more efficient water use and avoiding waste. Finally, plans might be needed for deciding how water is to be apportioned during drought conditions: when there is not enough to meet all demands, does priority go to households, industry, agriculture or nature (maintaining river flows)?

Coasts/Flooding sector

Climate change and sea-level rise make adaptation options for reducing flooding an important issue in all areas with developed coasts and floodplains. There are many hard options, ranging from very expensive and effective measures such as sea walls and storm surge barriers, to cheaper solutions such as groynes, artificial reefs, and beach replenishment. A 'softer' approach is to facilitate more natural coastlines and floodplains through a process of managed realignment, retreating flood defences to high ground or a new line of defence, allowing wetland habitats to develop and act as natural flood defences or storage. Smaller scale options include designed-in or retrofitted changes to building architecture, for example, water-resistant floor and wall coverings, storm porches and even buildings on 'terps' (artificially raised ground). Planning options include measures to restrict building on floodplains and in at-risk coastal areas. Other soft options could be used to encourage the use of small-scale flood resilience measures, to improve knowledge on how to react to flood events, and to institute early warning and evacuation systems.

Urban sector

There are a great many adaptation options in the urban sector, but in CLIMSAVE the focus is on the extent of urban building. Keeping urban areas compact (as opposed to 'sprawled' development) will reduce pressures on surrounding green space, make mass transit systems more efficient and can help ensure proximity to key facilities. However, it could also increase vulnerability to some factors such as heat waves. The main adaptation options for urban development include planning/zoning policy (restricting greenfield development, setting minimum density requirements), incentive policies such as taxes on second homes or tax breaks on letting, or policies to make urban living more attractive (better/cheaper facilities, higher taxation on private transport). facilities, higher taxation on private transport).

Biodiversity sector

There are many adaptation options with indirect (cross-sectoral) impacts on biodiversity, including increases in bioenergy crops, various agricultural and forestry options, and flood adaptation options (in particular managed realignment/wetland creation). In fact, most of the CLIMSAVE adaptation options influence land use/land cover in some way, and this will often have some positive or negative indirect impacts on biodiversity. The more specific biodiversity options in the IA Platform are primarily associated with increasing protected areas and with set-aside policy, i.e. policy to compensate farmers for leaving farmland out of production. There are many more detailed options – in particular, assisted migration/managed relocation and the creation/management of biodiversity corridors and networks to help species adapt to climate change – however, these more detailed and spatially-specific policies cannot be represented directly in the Platform.

Using the IA Platform to explore adaptation options: An illustration

To illustrate how the CLIMSAVE IA Platform can be used to investigate impacts and adaptation, we consider the direct and indirect effects of climate and socio-economic change on the forestry sector and on Scots Pine (*Pinus sylvestris L.*), a distinctive native pine of the Scottish landscape – the Caledonian Pine Forest of Scotland, in which the Scots pine is the dominant tree, is the only true native pine forest in Britain. Using a single illustrative climate change scenario within the IA Platform, the Scots Pine will face pressures due to the changing suitability of the climate (Figure 9). This pressure is compounded by a loss in simulated forest areas – the climate change scenario leads to a widespread reduction in the forested area within climatically-suitable areas (Figure 9).

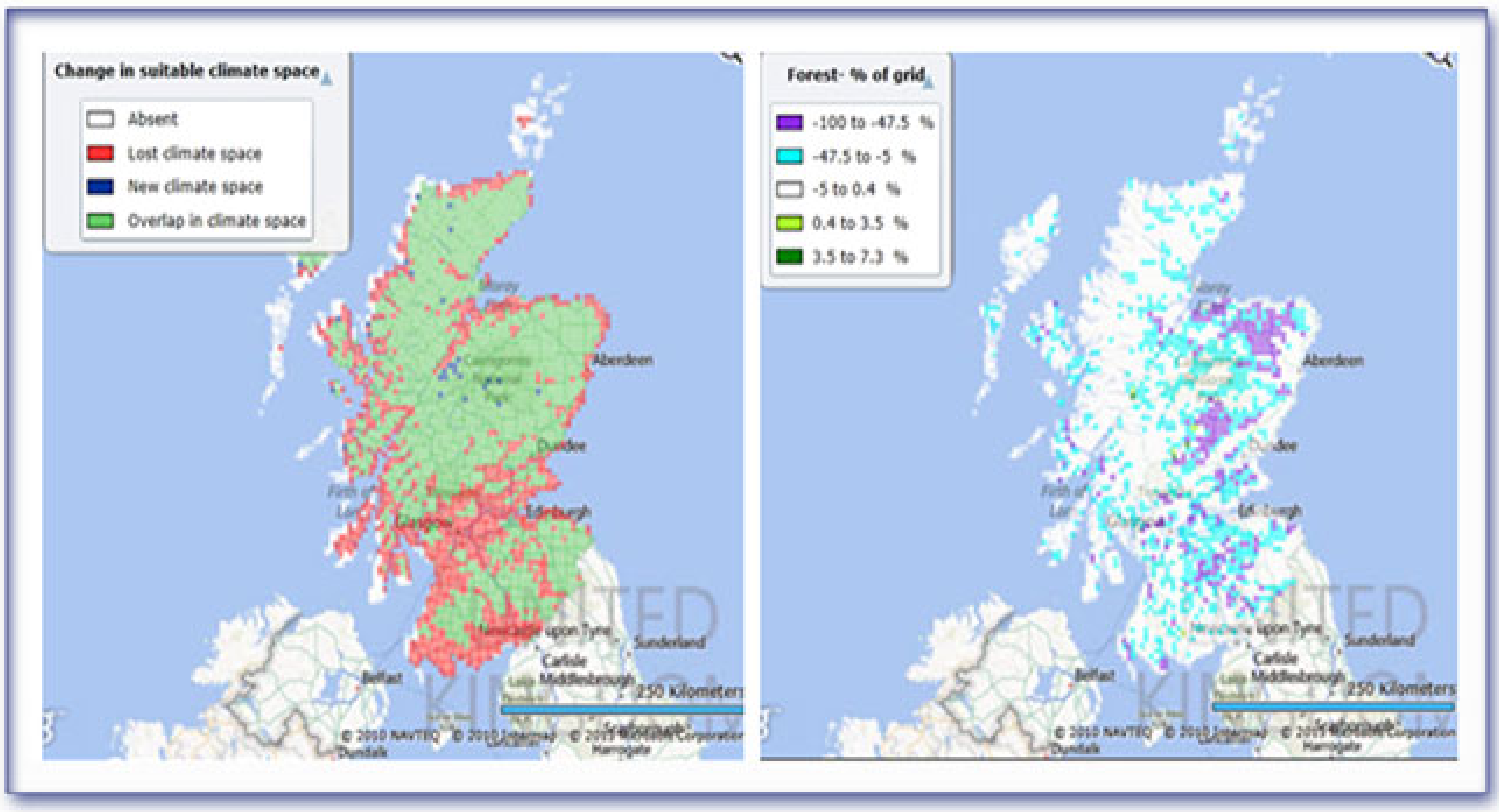


Figure 9: Illustrative example of the pressures from future changing climate suitability (left map) and reduced forest area (right map) for the Scots Pine in Scotland.

The CLIMSAVE IA Platform was used to investigate how two contrasting CLIMSAVE socio-economic futures (Mactopia and Tartan Spring; see pages 10-11) modify the forestry impacts due to climate change, and how these two futures affect the potential of adaptation to reduce the pressures within the forestry sector.

Without any adaptation, the Tartan Spring socio-economic scenario is shown in Table 4 to further reduce the forest area compared to climate change alone (-56% compared to -52%), in part due to land use change arising from the 35% expansion of the agricultural area. In contrast, Mactopia only slightly offsets the climate change impacts (-43% compared to -52%), even though the agricultural area has reduced as a consequence of effective agricultural innovation.

Adaptation within the agricultural sector to improve productivity, through the development of higher yielding crop varieties and improved mechanisation, reduces the agricultural area needed to meet the food demand in both scenarios, but has little effect on the forest area (or timber production) in Mactopia - the economic profitability of forestry in this scenario is insufficient to drive significant forest expansion into the land area no longer needed to meet food demand. Greater increases in forest area of up to 13% are seen within the lower GDP Tartan Spring scenario, but these are still insufficient to offset the impacts of future change on the forest area.

A much longer term adaptation strategy is to increase timber productivity through establishing tree species that are better suited to the future climate. In these cases, their higher yields increase the profitability of forestry leading to large expansion of forestry into the non-agricultural and agricultural areas and a net gain in forested area.

Table 4: Illustrative results of applying the CLIMSAVE IA Platform to investigate the effects of climate and socio-economic change on impacts and the potential for adaptation across Scotland.

	Change in forest area		Change in agricultural area (%)	
	MacTopia	Tartan Spring	MacTopia	Tartan Spring
Impact (relative to baseline) of:				
Climate change only	-52%		+34%	
Climate <u>and</u> socio-economic change	-43%	-56%	-17%	+35%
Effect of adaptation (relative to scenario impact):				
Promote bioenergy	< -1%	<1%	-14%	< 1%
Improvements in agricultural yields	2%	2%	-44%	< - 1%
Improvements in agricultural yields and mechanisation	3%	13%	-27%	-3%
Planting climate-optimum species	140%	149%	-10%	- 32%

The above example illustrates how the CLIMSAVE IA Platform enables the User to explore the effects of climate and socio-economic scenarios on sectoral and ecosystem service impact indicators, and to consider the potential for adaptation to offset these impacts. However, models such as the IA Platform cannot represent many of the processes involved in adaptation and it is important for the User to consider how such modelled strategies might be implemented in practice.

Reflection

The range of adaptation options is wide, with much variety in costs, capital requirements, applicability, effectiveness and secondary (synergistic and cross-sectoral) impacts. Details of the choices are scenario dependent, but also in many cases dependent on local details that cannot be captured in the large-scale modelling of CLIMSAVE. The Platform, therefore, seeks to examine broad trends in possible adaptation, not specific details. The cost-effectiveness screen (see pages 20-21) aims to help Platform users to consider these features at the broad (cross-Scotland) scale, offering a general understanding of the relative costs, potential (applicability) and effectiveness of the options, as well as of their cross-sectoral impacts. This is enough to sketch out broad scenarios for adaptation, and to inform the detailed assessment of specific adaptation plans that will be dependent on local conditions and constraints.

What are the costs of adaptation options?

Estimation of the costs and effects of adaptation options is an important step towards effective decision-making in the face of climate change. Climate change mitigation has the advantage of a clear unit of account – tonnes of emissions, weighted by greenhouse gas potential, most commonly expressed as tonnes of carbon dioxide equivalent. Calculating the cost of emissions control measures in monetary units per tonne saved (€ per tCO2e) enables comparison of the cost-effectiveness of different mitigation options. For adaptation there is no natural way to measure one 'unit' of adaptation that can be compared across different options within a single sector and, even more so, across different sectors. Nevertheless, the idea of cost-effectiveness in relation to adaptation remains important.

In the context of CLIMSAVE, adaptation options are modelled through changes in sliders in the IA Platform. Platform users test the impacts of possible adaptations by changing slider settings, and seeing how this changes the outputs that interest them. The sliders represent the combined effects of multiple possible adaptation measures. For example, the slider on flood resilience measures to reduce the amount of damages caused by a flood could be implemented through improvements to housing stock, development planning, retro-fitting or early warning systems. A list of possible adaptation options related to each slider was determined through stakeholder consultation and literature evidence. These included both 'hard' engineering options and 'soft' policy/behavioural changes.

The challenge was to capture evidence on the **costs** of each adaptation option, along with information on their effectiveness or **potential**, and on the **uncertainty** in the costs and potential, and to present this information to Platform users in a clear format that could help their thinking about the most appropriate choices (Figure 10). Furthermore, the different options could have quite different **cross-sectoral impacts** and, hence, it was necessary to develop a simplified account of these effects. Finally, adaptation options have different requirements, and might not be feasible under the conditions of particular socio-economic scenarios. Therefore, a way was needed to flag whether the availability of capital stocks (human, social, manufactured and financial capital) in a specific scenario future might limit the applicability of options or would not allow for their widespread use.

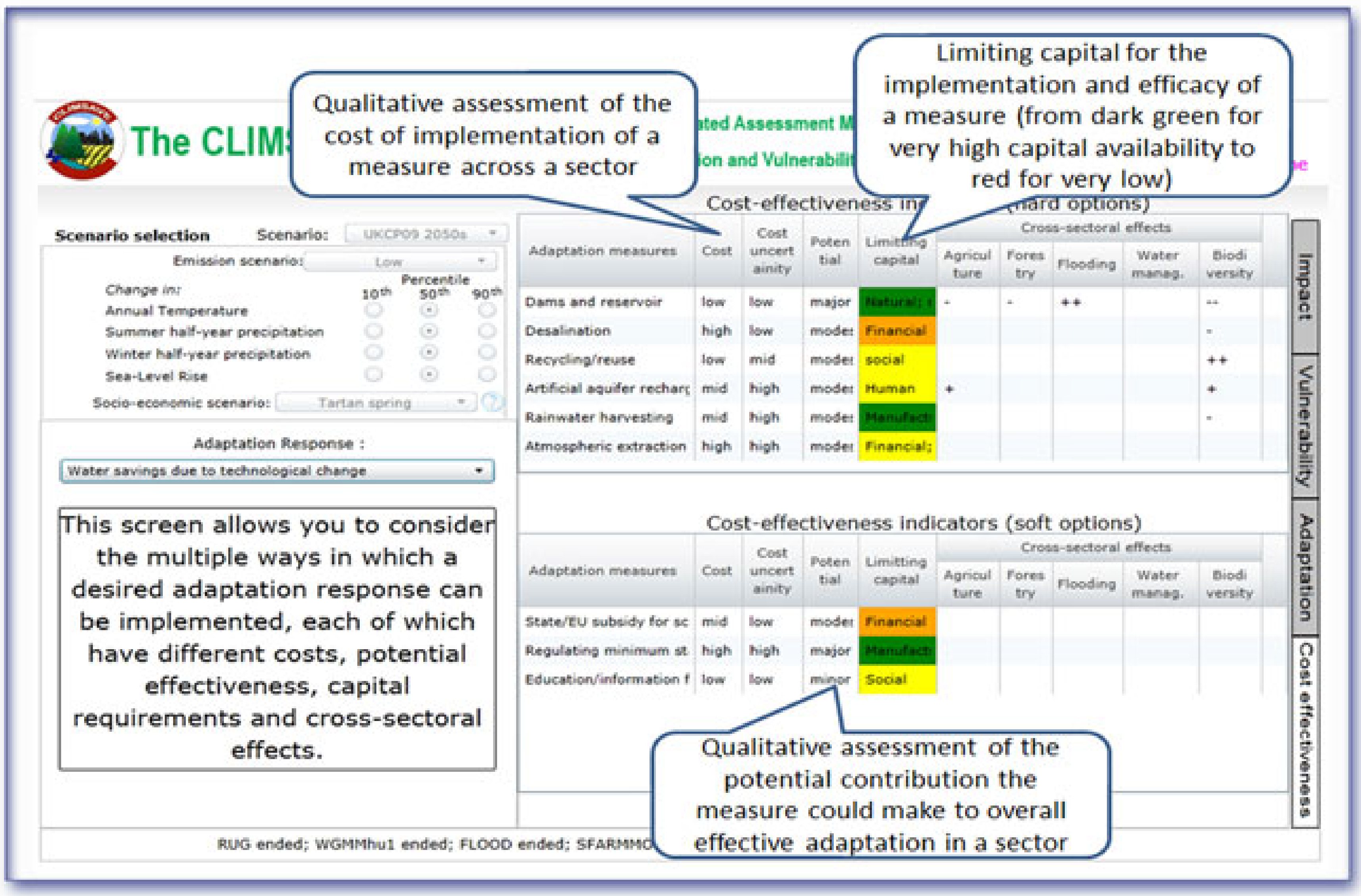


Figure 10: Cost-effectiveness screen of the IA Platform.

Information on these topics is quite rare: although there are many estimates of the costs of certain hard engineering options, these remain difficult to compare in terms of their effects, and there is little work on costs or effectiveness of soft adaptation options. There is even less information on the direction and intensity of cross-sectoral impacts, or on matches between different adaptation options and particular socio-economic scenarios.

CLIMSAVE researchers produced an extensive database of the costs of 'hard' adaptation options, drawing on hundreds of published studies from around the world. Where there are several studies of similar adaptation options, this allowed an assessment of the variability in costs, informing the assessment of the uncertainty of cost-effectiveness. The costs of 'soft' adaptation options were identified using expert judgement. The potential of hard and soft options to contribute to overall effective adaptation in a sector was also assessed using expert judgement, taking into account the way in which each slider affects the linked models underlying the IA Platform.

The feasibility of adaptation options within different socio-economic scenarios was partly tackled through stakeholder workshops, in which stakeholders identified the adaptation options thought most appropriate under different scenarios (see pages 10-11). Further work with stakeholders, indicator modelling and expert judgement led to the development of projections of capital levels under the scenarios and identification of limiting capitals for each adaptation option.

A new analytical tool, 'CrossAdapt', was developed and applied to gather information on cross-sectoral impacts. The tool was used to elicit expert judgment on the cross-sectoral effects of proposed adaptation measures in the six sectors of interest (agriculture, forestry, biodiversity, water, coasts and urban). The process targeted the effective elicitation of the type (positive or negative) and the intensity of cross-sectoral effects. As expected, experts express divergent views on a number of adaptation and cross-sectoral issues ('ambiguity effect'); this effect is lower in the urban, forestry and biodiversity sectors and higher in the water, agriculture and coastal sectors. Nevertheless, the CrossAdapt results help us to identify possible cross-sectoral impacts and to draw these to the attention of users of the CLIMSAVE IA Platform, ensuring that these potentially important impacts are considered.

Reflection

It remains impossible, with the current state of knowledge, to derive robust monetary measures of the cost-effectiveness of adaptation options at the Scottish scale and how these might alter if cross-sectoral impacts are taken into account. The costs and/or effectiveness of most options are not fixed, but are functions of local physical, social, governance and economic conditions. Presenting currency amounts for the costs or cross-sectoral impacts in the Platform would give a spurious veneer of accuracy and would run the risk that the results could be misused – for example, to argue that 'measure X is more cost-effective than measure Y when cross-sectoral impacts are taken into account' - when in fact such conclusions are rarely general, but rather depend on specific local conditions. This would not help the debate or advance strategic understanding of adaptation. It is wiser, therefore, to restrict the cost-effectiveness analysis to a qualitative description that helps Platform users to think about adaptation options, while leaving the numerical focus on impacts that are estimated more rigorously, and in a spatial framework, in the other screens of the Platform. The CLIMSAVE IA Platform is a strategic tool to aid thinking: it cannot, and does not, seek to replace more detailed local or regional analysis of the costs and benefits of specific adaptation options.

Where is Scotland most vulnerable to climate change?

For many policy and decision-makers, and other stakeholders, there is a need to better understand the future impacts of climate change and the related vulnerability of human and environmental systems. One of the main goals of adaptation is to reduce the future vulnerability to hazards associated with climate change, taking account of other socio-economic changes. Indicators are needed both to monitor progress in adaptation (process-based or upstream indicators) and to measure the effectiveness of adaptation (outcome-based or downstream indicators). Identification of vulnerability hotspots is an important form of outcome indicator, indicating where important vulnerabilities lie and how they might be tackled. Vulnerability is influenced by a wide range of factors - social, economic, political, cultural and environmental - and vulnerability indicators need to reflect this, while remaining feasible to calculate and implement.

Coping capacity and the vulnerability concept in CLIMSAVE

The CLIMSAVE approach to vulnerability hotspot mapping evaluates the spatially-variable impacts of future scenarios on human well-being. To do so it breaks vulnerability down into three key elements: (i) the severity of the impact itself; (ii) the level of adaptation in place to reduce the impact; and (iii) the extent to which humans are able to draw on their available resources (both tangible and societal) to cope with the impacts that remain, i.e. the "coping capacity". Vulnerability occurs where the level of impact following adaptation is greater than society's ability to cope.

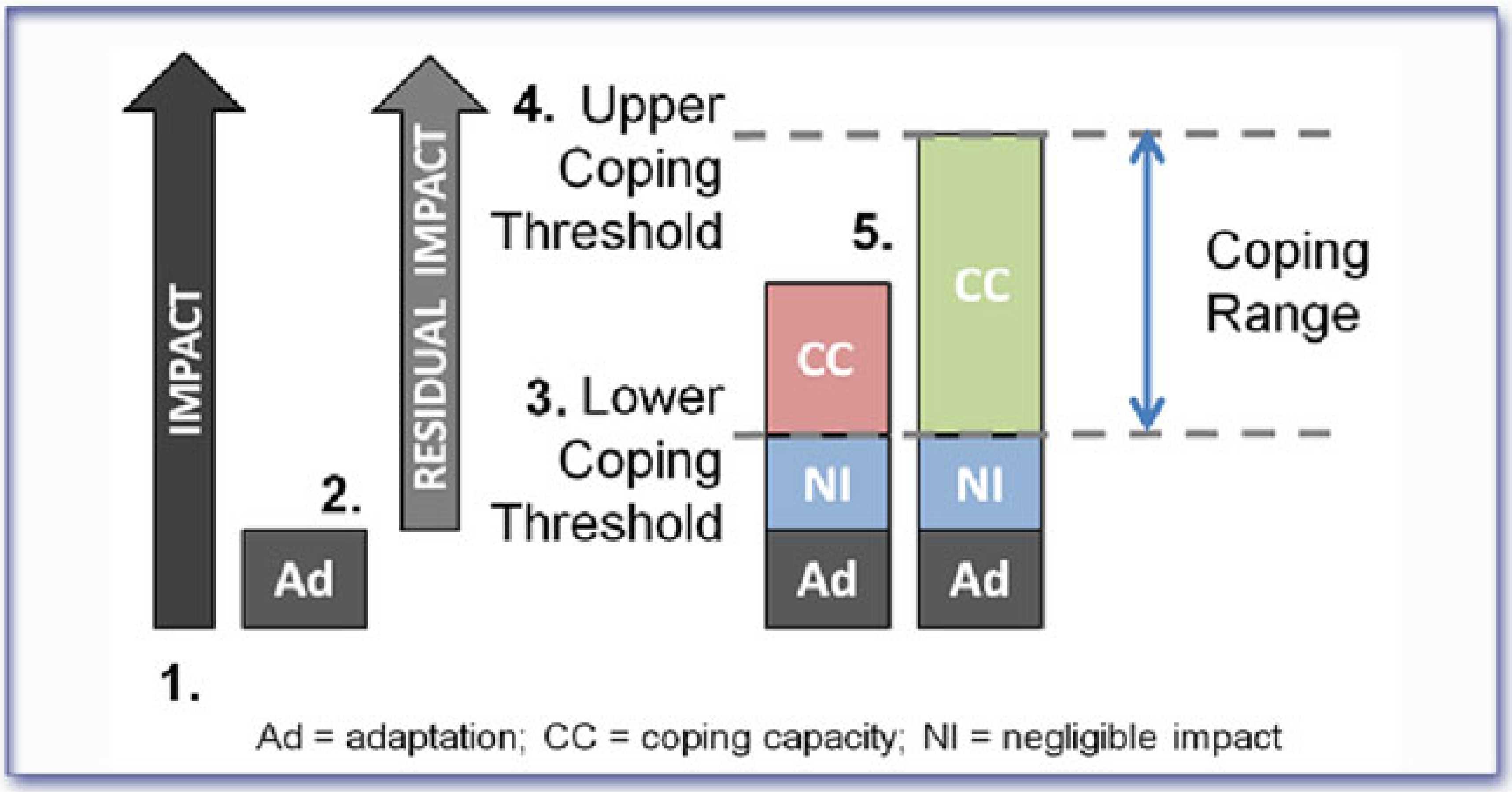


Figure 11: Schematic overview of the CLIMSAVE vulnerability approach.

This concept is shown schematically in Figure 11. Impact is modelled for a wide range of future scenarios (1 in Figure 11). Adaptation acts on the socio-economic scenario variables (for example, increasing the level of flood defence) and adaptive capacity changes with a scenario. The impact following adaptation is termed "residual impact", although the residual impact is the same as the "impact" if no adaptation is undertaken (2). The extent to which human well-being is affected by the residual impact depends on three further factors: (i) the "lower coping threshold" (the level of residual impact below which the impacts on human well-being can be considered negligible) (3); (ii) the "upper coping threshold" (the level of residual impact above which society is unable to cope, no matter how resource rich it is) (4); and, (iii) the "coping range" (the zone between the two thresholds) (5). Coping capacity reflects the available resources that are available to society and is derived as a function of human, social, financial and manufactured capital. Natural capital is not included in the coping capacity since it is calculated directly by the IA Platform.

Evaluating vulnerability in the CLIMSAVE IA Platform

Vulnerability is assessed for six ecosystem service indicators and composite indices to represent a cross-section of ecosystem service categories: (i) food supply (provisioning service); (ii) water exploitation index (provisioning service); (iii) people affected by a 1:100 year flood event (regulating service); (iv) a biodiversity index (supporting service); (iv) a land use intensity index (to represent cultural/aesthetic services); and (vi) a land use diversity index (to represent multi-functionality). Upper and lower coping thresholds were selected for each of these indicators/indices. Vulnerability occurs in areas where the significant residual impact is greater than the coping capacity, and a vulnerability index is calculated for each ecosystem service indicator/index at the grid cell level. Grid cells are classified as:

- ⇨ "Not vulnerable, negligible impact" (residual impact is less than the lower coping threshold);
- ⇨ "Not vulnerable, coping" (the significant residual impact is less than the coping capacity);
- ⇨ "Vulnerable, not coping" (the coping capacity is insufficient to deal with the significant residual impact); and
- ⇨ "Vulnerable, impossible to cope" (the residual impact is greater than the upper coping threshold).

The total vulnerable area and number of vulnerable people are calculated at the Scottish scale using the two vulnerable classes and summing the area and population of cells identified as vulnerable. Cross-sectoral aggregate vulnerability is calculated by counting the number of vulnerable sectors in each grid cell.

Mapping coping capacity

The majority of Scotland has a medium level of coping capacity for the baseline (Figure 12) with no particular geographic pattern distinguishing between the medium-low and medium-high classes. However, parts of the central belt have high coping capacity. Figure 12 also shows coping capacity for the CLIMSAVE socio-economic scenarios (see pages 10-11). The "Mactopia" scenario shows a marked improvement in coping capacity for both the 2020s and 2050s, which is entirely consistent with the positive outlook of this future world. Conversely, "Mad Max" shows considerable deterioration in coping capacity through the 2020s and the 2050s at which point most of the country has very low coping capacity. The "Tartan Spring" scenario has increasing coping capacity in the 2020s, but then declines from this level by the 2050s, but coping capacity is always better than for the baseline. Coping capacity in the "Scottish Play" scenario increases gradually through time.

Vulnerability hotspots

Figure 13 shows the aggregate vulnerability hotspot maps for a cool-wet and a hot-dry climate scenario for "Mad Max", which has the lowest coping capacity of all of the socio-economic scenarios. The warmer climate scenario has the effect of reducing the overall vulnerability in Scotland. This outcome was found consistently across the socio-economic scenarios, and suggests that Scotland might even benefit from some climate warming. The maps in Figure 13 demonstrate that only parts of Scotland are vulnerable to two indicators, which is less than for a similar study conducted for the whole of the European Union. The implication of this is that Scotland may be less vulnerable to climate change across a range of scenarios in comparison with the average response of the European Union. The areas with the most vulnerability are located in the Highlands and the southern uplands, with the vulnerability in these areas deriving from the combination of higher impacts and lower coping capacity. Areas with higher coping capacity (e.g. Aberdeenshire and the Lothians) have lower vulnerability compared to areas with a lower coping capacity. Much of the vulnerability in Scotland is driven by changes in food production. Where agricultural areas expand to accommodate increased food demand, the biodiversity index also benefits

since the index is made up primarily of agricultural habitat species. There is very little difference between the scenarios in terms of flood risk since this is strongly affected by location characteristics. Scotland is not vulnerable to water shortages under any climatic and/or socio-economic change scenario, either because the impact is too low or there is sufficient capacity to cope.

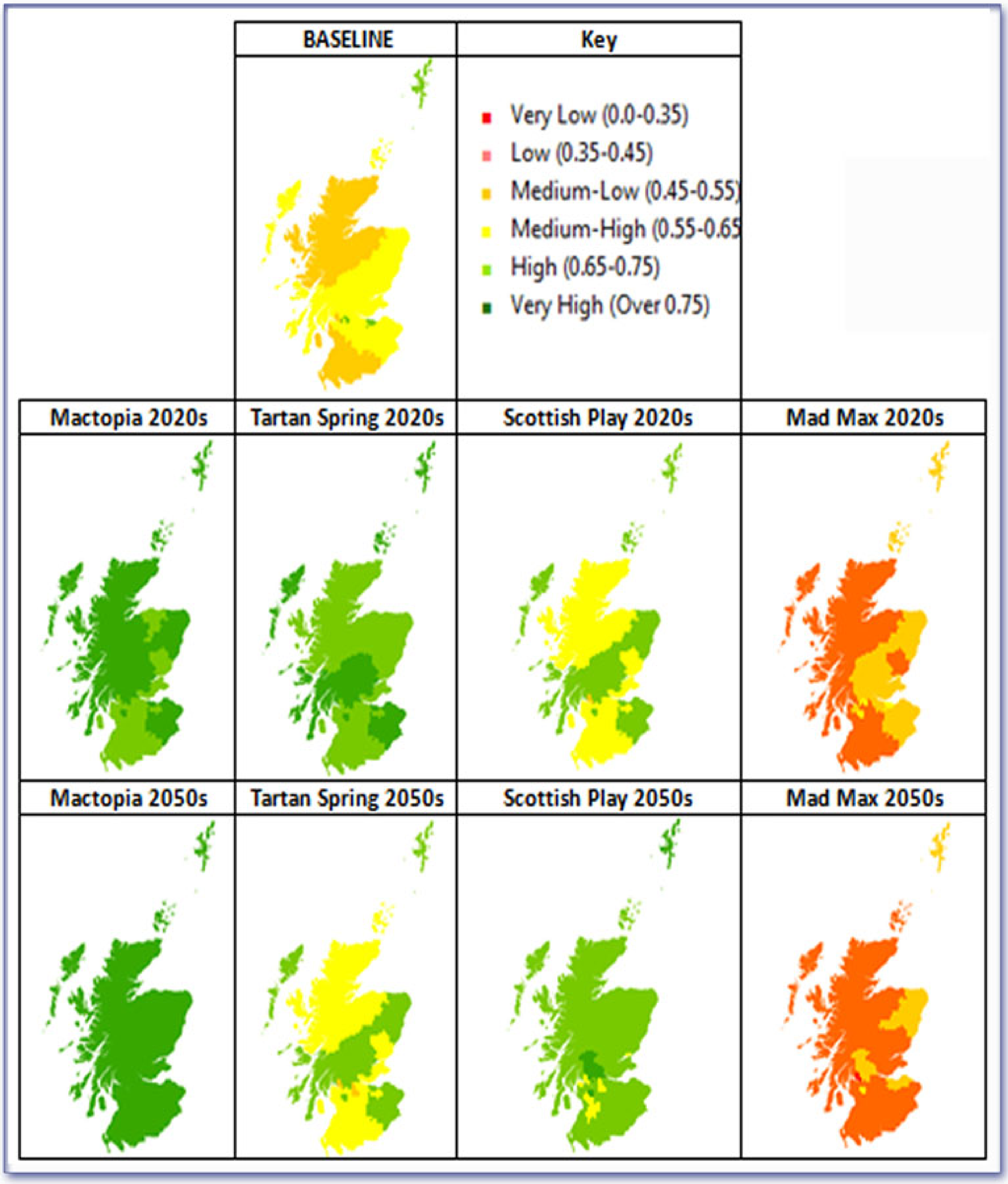
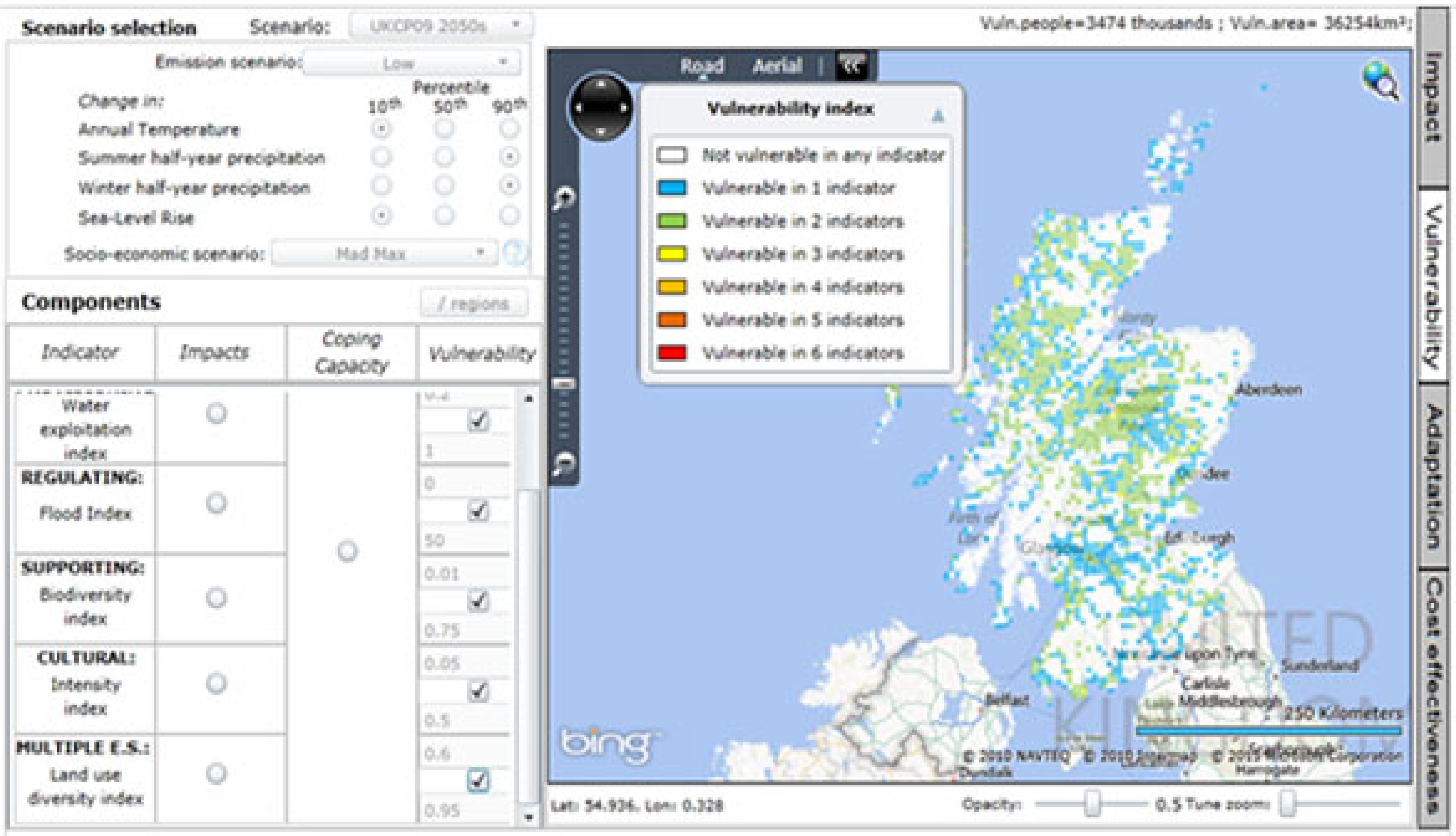
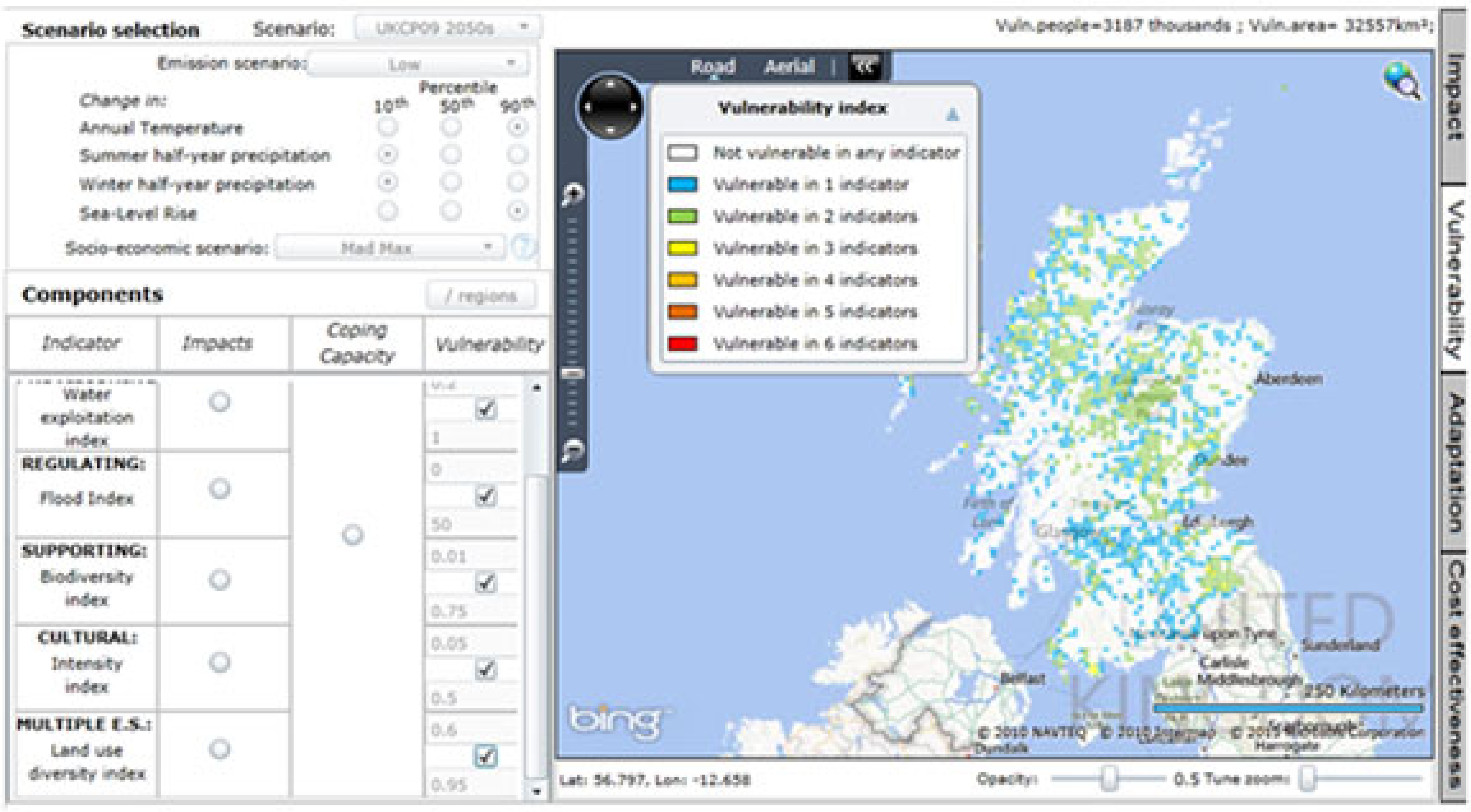


Figure 12: Coping capacity maps for Scotland for the baseline (upper map) and the CLIMSAVE socio-economic scenarios in the 2020s (middle maps) and 2050s (lower maps).



Scenario: Cool-wet climate scenario and the "Mad Max" socio-economic scenario for the 2050s.
Vulnerable people: 3,474,000 people; Vulnerable area: 36,254 km^2

Colour varies by number of sectors vulnerable: 0 1 2 3 4 5 6



Scenario: Hot-dry climate scenario and the "Mad Max" socio-economic scenario for the 2050s.
Vulnerable people: 3,187,000 people; Vulnerable area: 32,557 km^2

Figure 13: Scotland's aggregate vulnerability for a hot-dry climate scenario (lower map) and a cool-wet climate scenario (upper map) for the "Mad Max" socio-economic scenario in the 2050s.

Reflection

The CLIMSAVE approach to vulnerability assessment is replicable and transferable, and allows the integration of the concepts of capitals and coping capacity with stakeholder-derived scenarios. The approach produces patterns of coping capacity that might be expected for the socio-economic scenarios. The aggregate vulnerability hotspot maps for Scotland suggest that human well-being may benefit from climate change with vulnerability reducing for warmer climate scenarios across a range of socio-economic scenarios. Vulnerability is greatest where coping capacity is low (e.g. the Highlands and southern uplands) and lowest where coping capacity is high (e.g. Aberdeenshire and the Lothians).

Which adaptation policy strategies are robust to uncertain futures?

There is an increasing amount of research on policy robustness in the area of climate change adaptation. Such studies look at the effect of uncertainties about future climate change, technological advances and socio-economic development on policy responses in order to find adaptation responses that can be most effective in the long-term. The overall aim of this work in the CLIMSAVE project was to examine whether adaptation responses are robust, by looking at whether they would reduce vulnerability to climate and socio-economic changes across sectors, scales and scenarios.

For this analysis a robust policy measure was defined as one which has benefits across sectors, scenarios and spatial scales. A benefit is an improvement in human well-being through a reduction of vulnerability to climate and socio-economic change. The sectors examined are those for which vulnerability to changes are assessed in the CLIMSAVE IA Platform: food provision, water exploitation, flooding, biodiversity, land use intensity and land use diversity (see pages 22-25). The scenarios examined are four climate scenarios derived from the UK Climate Projections 2009 representing hot-dry, hot-wet, cool-dry and cool-wet possible climates (see pages 8-9) and the four CLIMSAVE socio-economic scenarios for Scotland: Mactopia, Tartan Spring, Mad Max and The Scottish Play (see pages 10-11). The robustness of policies across scale can be determined by comparing the results for Scotland with those for Europe.

Clustering the adaptation options from the CLIMSAVE IA Platform

It is not possible to test the effects of policies within the CLIMSAVE IA Platform, but rather to test adaptation options. Therefore, for the robustness analysis the options available on the IA Platform were clustered into so-called "policy archetypes". Four archetypes were defined:

⇨ **Ecosystem-based Adaptation (EbA)**: The goal of EbA is to protect or improve the integrity and health of ecosystems and habitats so that nature retains capacity for adapting to changing complex pressures and conditions, such as climate change.

⇨ **Market-based Adaptation (MbA)**: The major objectives of market-based adaptation (MbA) are fund raising, for example through taxes/market mobilisation for adaptation activities; efficient allocation of funds that are available for projects aiming to avoid climate change related damages; promotion of adaptation by various stakeholders; and sharing of financial risks in the context of climate change (e.g. transfer of risks through insurance-based mechanisms).

⇨ **Technology-based Adaptation (TbA)**: The goal of TbA is to adapt to climate change and variability through the development and use of technology such as irrigation, flood defences and advanced early warning systems.

⇨ **People-based Adaptation (PbA)**: The goal of PbA is to adapt to climate change and variability using human and social capital. This includes education and awareness-raising, building of networks to respond to climate change and changing institutions (including regulation).

Testing the robustness of policy archetypes using the CLIMSAVE IA Platform

Table 5 shows how the adaptation options from the IA Platform were clustered for each archetype. Some measures are included in more than one archetype. So, for example, water demand prioritisation is

included in both the EbA and the MbA archetypes. For the EbA archetype, the environment was set as the priority sector for water to maintain minimum environmental flows, while for MbA the priority was set to domestic/industrial uses. The flood risk adaptation approach was set to "Retreat" for EbA, "Mixed" for MbA, "Upgrade" for TbA and "Resilience" for PbA. The reasoning behind these choices is that "Retreat" opens space for ecosystems, "Upgrade" is clearly a technological approach of building infrastructure, "Resilience" satisfies the needs of people for a safe environment, while "Mixed" is open to the use of market mechanisms. For each policy archetype, the slider for each measure was changed to the maximum amount that was credible for each socio-economic scenario. The tests were all carried out for the 2050s timeslice.

Table 5: Adaptation options from the IA Platform included in the four policy archetypes.

EbA	MbA	TbA	PbA
Water demand prioritisation to the environment	Water demand prioritisation for domestic/industrial use	Water savings due to technological change	Water savings due to behavioural change
Reduce diffuse source pollution from agriculture	Increase food imports	Reduce diffuse source pollution from agriculture	Reduce dietary preferences for beef and lamb
Protected Area (PA) changed by increasing the number of PAs to improve connectivity and by increasing the size of existing PAs		Improvements in irrigation efficiency	Reduce in dietary preference for chicken and pork
Increasing the amount of Protected Area allocated to forest and agriculture land uses		Improvements in agricultural yields	Increase social capital
Increase compact development		Improvements in agricultural mechanisation	Increase human capital
Flood risk management adaptation approach: Retreat	Flood risk management adaptation approach: Mixed	Flood risk management adaptation approach: Upgrade	Flood risk management adaptation approach: Resilience
Increase in bioenergy production	Forest management for 5 tree species: Even-aged	Forest management for 5 tree species: Optimum	Forest management for 5 tree species: Uneven-aged
		Increase manufactured capital	

For each scenario, the IA Platform was run without any adaptation and then with each of the policy archetypes separately. The results were compared using the **total number of vulnerable people** (see pages 22-25) for each of the IA Platform sectors (food provision, water exploitation, flood, biodiversity, land use intensity and land use diversity).

Results of running the four policy archetypes through the IA Platform are shown in Table 6 for four sectors. The number of vulnerable people when no adaptation is implemented is shown in the first row of the table. The ability of the policy archetypes to reduce the number of vulnerable people is indicated by the green coloured cells of the table. Some policy archetype actually increased vulnerability (red coloured cells of the table) due to feedbacks and interactions between the sectors (see pages 12-15). White cells indicate that vulnerability does not differ from when no adaptation has been implemented.

Table 6: Results of the policy robustness analysis showing the number of people vulnerable (rounded to the nearest ten) for three sectors, two socio-economic scenarios (Tartan Spring and Mad Max) and two climate scenarios (UKCP09 hot-dry and cool-wet).

Sector:	Biodiversity				Flooding			
Socio-economic Scenario:	Tartan Spring		Mad Max		Tartan Spring		Mad Max	
Climate scenario:	Hot-dry	Cool-wet	Hot-dry	Cool-wet	Hot-dry	Cool-wet	Hot-dry	Cool-wet
No adaptation	8360	3040	6900	6100	1900	720	320	320
EbA	7420	3040	7560	6560	1900	720	320	320
MbA	9310	1990	8550	6810	1900	720	320	200
TbA	9880	5620	1037	7660	980	720	768	470
PbA	5070	1120	5900	5190	715	570	320	200

Sector:	Food Provision			
Socio-economic scenario:	Tartan Spring		Mad Max	
Climate scenario:	Hot-dry	Cool-wet	Hot-dry	Cool-wet
No adaptation	3561	4388	2802	3404
EbA	3586	4325	2844	3439
MbA	3702	4080	3070	3530
TbA	3468	4432	3014	3618
PbA	3378	3834	2595	3316

⇨ **Robustness across scales**: Comparing the results with those for Europe, it can be seen that each of the policy archetypes has at least one indicator for which the total number of vulnerable people is lower than with no adaptation. At this very broad level, therefore, each of the archetypes reduces vulnerability with respect to at least one indicator, which suggests that there is robustness with respect to geographical scale.

⇨ **Robustness across socio-economic scenarios**: For the biodiversity indicator only the PbA archetype reduces vulnerability in both socio-economic scenarios. For the flood indicator, PbA reduces vulnerability in both socio-economic scenarios combined with the cool-wet climate scenario. For the food provision indicator, again only the PbA archetype reduces vulnerability in both socio-economic scenarios. Overall therefore, the PbA archetype reduces vulnerability across socio-economic scenarios most frequently. As can be seen in Table 6, the PbA archetype includes increasing both human and social capital, which increases coping capacity and thus reduces vulnerability even in scenarios such as Mad Max, in which society is very divided and resources are scarce.

⇨ **Robustness across climate scenarios**: Comparing the results of the hot-dry and cool-wet scenarios shows that the PbA archetype reduces vulnerability for both climate scenarios for two of the three vulnerability indicators, but not for the flood indicator, where vulnerability remains the same in the hot-dry scenario for Mad Max. Overall therefore, the PbA archetype reduces vulnerability across climate scenarios most frequently.

⇨ **Robustness across sectors**: EbA reduces vulnerability for only two sectors. In particular EbA does not reduce vulnerability to flooding in any combination of socio-economic and climate scenarios. TbA only reduces vulnerability in two sectors and only in the Tartan Spring scenario. PbA reduces vulnerability in all sectors in the cold-wet scenario. Overall, the PbA archetype reduces vulnerability in all sectors for all, but one, scenario.

Testing adaptation options not included in the CLIMSAVE IA Platform

There are many "soft" adaptation options that are not included in the IA Platform, so these were incorporated into the assessment of policy robustness using expert judgement. The options were sorted according to policy archetype. For example, education belongs to the PbA archetype, while insurance schemes belong to the MbA archetype. A qualitative assessment was then made of the effectiveness of the resulting clusters.

The sorting of the options showed that they belonged either to the PbA (e.g. education, early warning systems, institutional change) or MbA (e.g. taxes, subsidies, insurance) archetypes. The PbA options that use and build human capital are not necessarily robust across sectors. For example, labelling in the forest sector could influence water and biodiversity. The PbA options are considered to be robust across spatial scales. However, they are probably not robust across socio-economic scenarios, since the Tartan Spring and Mad Max scenarios have strongly declining human capital in the 2050s and thus human capital would be a limiting factor for the effectiveness of the PbA archetype. The PbA options that use and build social capital through developing institutions and regulations are not necessarily robust across sectors, since regulations for one sector (e.g. coastal or urban) can affect another sector (e.g. agriculture or forestry). They are robust across scales, since the regulations and policy initiatives are in principle applicable at the EU and regional level. They are not robust across socio-economic scenarios, since governance differs in the scenarios. There is very weak governance in the Mad Max scenario, while in the Mactopia scenario governance is strong. The MbA options are not robust across sectors because of cross-sectoral impacts. For example, changes to agricultural subsidies can affect water, forests, biodiversity, etc. They are perhaps not robust across socio-economic scenarios, since three of the socio-economic scenarios have declining financial capital towards 2050 and only Mactopia has increasing financial capital that could be mobilised for the options that draw on financial capital. Furthermore, the scenarios have very different levels of governance that would affect the implementation of many taxation options.

Reflection

The results show that the use of policy archetypes enables an analysis of policy robustness across scales, sectors and scenarios using the CLIMSAVE IA Platform and expert judgement. The results presented here suggest that People-based Adaptation is more robust than Ecosystem-based, Market-based and Technology-based Adaptation. The effectiveness of PbA is related to the fact that it includes the options that increase both human and social capital, which thus increases coping capacity. The method used here was designed to identify the differences between archetypical policy strategies and to test the robustness of these. In practice, however, policy is based on a range of options that combine elements of the different archetypes. The archetypical results provide, therefore, the basis for understanding how different policy options might be combined to best reduce climate change vulnerability.

Why adaptation and mitigation need to be integrated?

Adaptation and mitigation are two complementary ways of addressing climate change. Adaptation seeks to reduce the impacts of climate change, while mitigation decreases greenhouse gas emissions or increases carbon storage. CLIMSAVE reviewed a selection of adaptation and mitigation measures for the agriculture, biodiversity, coastal, forestry, urban and water sectors to identify their impacts, how these interact with other sectors, and measures which could enhance both adaptation and mitigation.

It found that almost all measures had an impact beyond the original intended one and that these additional impacts could be in the same sector, but often involved one or more other sectors. For example, coastal adaptation measures, such as managed realignment and restoration projects, tend to impact on biodiversity via the creation of valuable intertidal habitat, as well as providing carbon storage for mitigation.

Examples were found of neutral, positive and negative impacts on the affected sector(s). Few measures had little or no direct impact, although in the urban sector, building measures, such as natural ventilation, insulation and painting surfaces white, have little or no effect on adaptation or mitigation in other sectors, nor do many biodiversity adaptation measures. These are no-low regret options and provide benefits despite climate change uncertainties (Table 7). The highest number of interactions between sectors was positive, with many benefitting adaptation in the biodiversity and water sectors. For example, stormwater management in urban areas using different types of greenspace, such as green roofs, Sustainable Urban Drainage Systems (SUDS) and urban trees can have numerous benefits for biodiversity. In addition to helping urban areas adapt, they can reduce adaptation needed by the biodiversity sector.

Some measures not only contribute to adaptation in other sectors, but also to mitigation, as in the example of coastal adaptation above. Major synergies between adaptation and mitigation also exist for agriculture through reducing greenhouse gas emissions by improving nitrogen use efficiencies and soil carbon storage. Measures include some forms of conservation agriculture, reducing soil erosion, soil moisture conservation and land use changes involving abandonment or less intensive agriculture. Also, the restoration of freshwater wetlands, such as peat bogs, to manage water flows could contribute to biodiversity adaptation and mitigate climate change.

Many negative interactions also related to biodiversity and water. For example, no-tillage systems may negatively affect native species, as may some forestry planting and operations, while coastal hard-engineering could prevent ecosystems migrating inland in response to sea-level rise. Possible conflicts with water include afforestation on new land for carbon storage or crop irrigation which can increase water demand, while increasing water supply is needed to meet demands of urbanisation or economic activities. All these changes can impact biodiversity, especially river and wetland species/habitats, and their ability to adapt. These negative impacts may lead to trade-offs, for example between maintaining water levels for biodiversity and agriculture and domestic or industrial supply. For coasts they may relate to managed realignment, where the trade-off is between maintaining the current primary habitat and sustainable coastal defence. For forestry they may be between afforestation for carbon storage and water supply.

Table 7: Adaptation measures for the sectors and their interactions and impacts. No-low regrets: ++ indicates measures that will produce benefits regardless of climate change, + indicates no-regret in some cases, depending on circumstance.

Sector	Examples of adaptation options	No-low regret	Reversible / flexible	Synergies with mitigation	Synergies with adaptation in other sectors
Agriculture	Changing planting dates	+	✓		
	Genetic modification		×	✓	
	Conservation agriculture	+		✓	✓
Urban	Green infrastructure	++	✓	✓	✓✓
	Building measures	++	×	✓	
Water	SUDS	++		✓	✓✓
	Flood defences		××		✓
	Storage	+			
	Floodplain restoration	+		✓	✓
Biodiversity	Increasing habitat connectivity	++	✓	✓	✓✓
	Restoration schemes	++		✓	✓
	Habitat creation	+		✓	✓
Forest	Afforestation with climate-resilient tree genotypes	+	×	✓✓	✓
Coastal	Hard-engineering		××	×	
	Managed realignment	+		✓	✓
	Wetland creation	+		✓✓	✓✓

Reflection

Very often interactions with adaptation and mitigation measures in other sectors were not explicit, thus many opportunities of positive interactions are not taken into account in any assessment of the success of measures. An integrated approach to adaptation and mitigation is needed, therefore, so that measures with beneficial cross-sectoral interactions, which may also be more cost-effective, are implemented as well as avoiding negative cross-sectoral interactions. Since many interactions involved biodiversity and water, these may be good sectors to start with and already ecosystem-based adaptation for climate change is being promoted.

CLIMSAVE was a research project funded by the European Commission to assess climate change impacts, adaptation and vulnerability across six key sectors: agriculture, forestry, biodiversity, urban, water and coasts. This report summarises the key findings from this integrated approach, many of which were produced using the interactive web-based tool, the CLIMSAVE Integrated Assessment Platform. Two versions of the tool have been developed: one for Scotland and one for Europe. The Scottish tool is publically available from the CLIMSAVE website (www.climsave.eu) or the Climate-Adapt website (http://climate-adapt.eea.europa.eu/). This tool allows stakeholders to explore and understand climate change impacts and adaptation for themselves.

CLimate change Integrated assessment Methodology for cross-Sectoral Adaptation and Vulnerability in Europe

www.climsave.eu
Contract Number: 036890

Published by TIAMASG (Bucharest) in 2013