Evaluation of existing climate and socio-economic scenarios including a detailed description of the final selection

Deliverable D2.1

April 2015

Kasper Kok[1], Jens Hesselbjerg Christensen[2], Marianne Sloth Madsen[2], Simona Pedde[1], Marc Gramberger[3], Jill Jäger[4] and Tim Carter[5]

[1] Wageningen University, the Netherlands
[2] Danish Meterological Institute, Denmark
[3] PROSPEX, Belgium
[4] Independent, Austria
[5] Finnish Environment Institute (SYKE), Finland

IMPRESSIONS – Impacts and Risks from High-End Scenarios: Strategies for Innovative Solutions (www.impressions-project.eu)

Prepared under contract from the European Commission

Contract n° 603416
Collaborative project
FP7 Environment

Project acronym:	**IMPRESSIONS**
Project full title:	**Impacts and Risks from High-end Scenarios: Strategies for Innovative Solutions**
Start of the project:	01 November 2013
Duration:	60 months
Project coordinator:	University of Oxford
Project website	www.impressions-project.eu
Deliverable title:	Evaluation of existing climate and socio-economic scenarios including a detailed description of the final selection
Deliverable n°:	D2.1
Nature of the deliverable:	Report
Dissemination level:	Public
WP responsible:	WP2
Lead beneficiary:	Wageningen University (WU)
Citation:	Kok K, Hesselbjerg Christensen J, Sloth Madsen M, Pedde S, Gramberger M, Jäger J & Carter T (2015). *Evaluation of existing climate and socio-economic scenarios*. EU FP7 IMPRESSIONS Project Deliverable D2.1.
Due date of deliverable:	Month 18
Actual submission date:	Month 18

Deliverable status:

Version	Status	Date	Author(s)
1	Draft	16 March 2015	Jens Hesselbjerg Christensen, Marianne Sloth Madsen, Kasper Kok
2	Draft	24 April 2015	All authors
3	Final	28 April 2015	All authors and Paula Harrison

The content of this deliverable do not necessarily reflect the official opinions of the European Commission or other institutions of the European Union.

Table of contents

Preface

The overall objective of WP2 is to develop multi-scale, integrated climate and socio-economic scenarios for five case studies (global/central Asia, Europe, Scotland, Iberia and Hungary), including high-end climate change scenarios and more extreme socio-economic scenarios. A first crucial step in this process is stocktaking of the available existing scenarios that could serve to inform and steer the scenario development process. This deliverable reports on the activities related to Task 2.1 and includes an evaluation and comparison of existing socio-economic and climate scenarios in each of the case study areas and an analysis of how the new IMPRESSIONS scenarios could build on existing material. As the title suggests, the emphasis is on reporting on existing material. Yet, as the work in Task 2.1 progressed, it expanded somewhat beyond the original description. Important elements that were included in the work and that are reported in this deliverable are:

- A procedure to systematically provide an overview of existing climate change scenarios;
- An assessment of existing socio-economic scenarios and the methods they employed for informing the choice of socio-economic scenarios;
- A presentation of the European socio-economic scenarios, resulting from an expert meeting in January 2015;
- An initial elaboration on the combination and integration of climate and socio-economic scenarios.

Summary

This deliverable documents the assessment of existing climate and socio-economic scenarios at multiple scales and the selection procedure for the starting set of scenarios. The new global scenarios consisting of Representative Concentration Pathways (RCPs) and Shared Socio-economic Pathways (SSPs) were selected as a starting point for scenario development. Although using a very recent set of scenarios comes with the risk of using products that might not live up to expectations, the RCP x SSP set is the only sufficiently recent set of global scenarios that extend until 2100, that are directly related to climate change, and that offer socio-economic scenarios of sufficient detail.

Five combinations of RCPs and SSPs were selected as the best starting points for integration of climate and socio-economic scenarios:

- RCP8.5 x SSP5
- RCP8.5 x SSP3
- RCP4.5 x SSP3
- RCP4.5 x SSP4
- RCP4.5 x SSP1

These cover moderate and strong climate change, as well as future societies with high and low challenges to adaptation and mitigation. The selection allows analysis of the effects of different RCPs combined with the same SSP, and the effects of different SSPs combined with the same RCP. Furthermore, low adaptation challenges (SSP1/5) and high adaptation challenges (SSP3/4) are confronted with both RCPs.

The climate change scenarios will be based on climate model simulations that are available from CMIP5 and CORDEX for RCP8.5 and RCP4.5 due to the focus in IMPRESSIONS on high-end climate change. To select a limited number of climate model simulations as a core set that will be applied in all case studies, climate model sensitivity (reflecting lower, intermediate and high-end climate change) and the availability of regional model data (reflecting the need for daily data in the local

case studies) were used as key criteria. To meet these criteria, we examined those GCMs which have been downscaled in CORDEX by at least one regional climate model. This resulted in the following selection of the core set of climate scenarios:

- Representing high-end climate change: RCP8.5 x HadGEM2-ES/RCA4, RCP8.5 x CanESM2/CanRCM4 and RCP8.5 x IPSL-CM5A-MR/WRF;
- Representing intermediate climate change: RCP8.5 x GFDL-ESM2M/RCA4 and RCP4.5 x HadGEM2-ES/RCA4;
- Representing lower-end climate change: RCP4.5 x GFDL-ESM2M/RCA4 and RCP4.5 x MPI-ESM-LR/CCLM4.

The socio-economic scenarios will be based on the SSPs in all case studies, but the existence of other relevant scenarios in the different case study regions was also assessed. For the European and Scottish case studies, the CLIMSAVE scenarios were selected as being highly relevant. We then matched the four CLIMSAVE socio-economic scenarios with the global SSPs and extended them until 2100. For both case studies, it proved difficult to match SSP5 (Fossil-fuelled Development) with the CLIMSAVE scenarios, so this is being developed based on the global SSP storyline. However, SSP1 (Sustainability) and SSP3 (Regional Rivalry) matched well and SSP4 (Inequality) matched in part, so elements of both scenario sets are being combined. For the other case studies (Hungary, Iberia and central Asia – referred to as EU-external), no existing scenario sets were identified that were sufficiently similar to the SSPs to be used as a starting point. Existing scenarios were either simply not available (Hungary and EU-external), did not have the right focus, were not developed at the right spatial and/or temporal scale, or did not contain details on socio-economic futures. Thus, for these case studies, participatory scenario development will start from scratch taking account of the existing global SSPs and the European SSPs which are being developed within IMPRESSIONS.

The integration of the climate and socio-economic scenarios is in its early stages. Integration of SSPs and RCPs has been discussed with IMPRESSIONS partners. Because there is a strong link between a particular RCP and SSP, it was decided to confront stakeholders in the IMPRESSIONS workshops with climate change (impacts) early in the participatory process and to include their views in the integration process.

1. Introduction

This report is divided into four main parts. Chapter 2 introduces the new global scenarios consisting of Representative Concentration Pathways (RCPs) and Shared Socio-economic Pathways (SSPs). Chapters 3 and 4 report on climate and socio-economic scenarios in the IMPRESSIONS case studies, respectively, and Chapter 5 provides some first indications on how climate and socio-economic scenarios can be integrated. There is an emphasis on larger scale information, particularly for the global and European scale, because more information from existing scenario exercises is available at these scales. Socio-economic scenarios have an additional focus on Scotland, a case that is continued from an earlier FP7 project, CLIMSAVE.

Two main sources of existing information have been considered both for socio-economic and climate scenarios. First, the new global scenarios consisting of Representative Concentration Pathways (RCPs) and Shared Socio-economic Pathways (SSPs) were identified during the proposal writing phase as an important starting point to guide scenario development (see Chapter 2). Second, IMPRESSIONS explicitly builds on scenario development that was started during the CLIMSAVE project for two case studies, Europe and Scotland (see Chapter 3). Given the significant resources available through the RCP/SSP or CLIMSAVE material, other scenario exercises have been assessed in the light of their compatibility with these two starting points.

2. Introduction to the new global scenarios: The RCP x SSP scenarios

This chapter provides a short overview of existing global scenarios and the development process of the new global scenarios, referred to here as the RCP x SSP scenarios, as background to the subsequent chapters on climate and socio-economic scenarios, where more detailed descriptions are given. Additionally, a summarising overview is given of the (combinations of) RCPs and SSPs that were selected to be used in IMPRESSIONS.

2.1. Existing scenarios and selection of a best set

A small set of existing global scenarios was evaluated for their usefulness within IMPRESSIONS. We opted for a small set only, given the strong preference, also expressed in the Description of Work of IMPRESSIONS, for the RCP x SSP scenarios. An evaluation against other existing global scenarios was undertaken in order to better understand the strengths and weaknesses of the RCP x SSP scenarios. Besides the RCP x SSP scenarios, the global scenarios included were:

- IPCC Special Report on Emission Scenarios. (IPCC SRES; Nakićenović et al., 2000). Focus: climate and greenhouse gas emissions. This is the most used and most well-known of all scenario sets in existence. It is global but has been used as the starting point for many continental and national scenario sets.
- Millennium Ecosystem Assessment (MA; MA, 2005). Focus: ecosystems and ecosystem services. This set of four scenarios does not specifically include information related to climate change (impacts), but the socio-economic scenarios are very elaborated and include an unmatched detail on changes in land-based systems.
- Global Environment Outlook (GEO-3, GEO-4; UNEP, 2002, 2007). Focus: integrated view on the environment. An important strong point is the availability of storylines for Europe, as socio-economic scenarios were developed at the continental level.
- Shell scenarios (Shell, 2008). Focus: energy. The lack of specificity for Europe and the minimal use of quantitative models are important drawbacks. These scenarios have been mostly included because of the focus on the energy sector and the distinctly different (business) starting point.

Additional sets of (more recent) global scenarios were included only in an initial screening. Interesting work includes recent initiatives related to the Global Scenario Group (see www.gsg.org); the World Water Scenarios developed and further explored at IIASA; and the World Energy Scenarios developed by the World Energy Council. None was deemed sufficiently useful to include in this evaluation.

Table 2.1 provides the criteria used for the evaluation and the scores for the global scenarios that were included. From the results, the most important conclusion is that the RCP x SSP scenarios are most useful for adoption in IMPRESSIONS, although scores differ relatively little. The Shell scenarios scores lowest, mostly based on an overall lower scoring in many important categories, such as scientific acceptance, degree of quantification, and specificity for Europe. In relation to the RCP x SSP scenarios, the following conclusions seem valid.

Table 2.1: Criteria for usefulness for IMPRESSIONS and scores for existing global scenario sets.

Criteria	**RCP x SSP**	**IPCC SRES**	**MA**	**GEO-4**	**Shell**
Degree of detail in stories	5	5	8	6	6
Specificity for Europe	2	4	2	5	2
Time horizon	9	6	8	8	8
Degree of quantification	6	9	7	6	4
Scientific acceptance	6	9	8	8	5
Acceptance by policy-makers	8	8	5	6	6
Information on relevant sectors	8	8	7	5	6
Degree of 'currentness'	10	2	3	4	6
Availability	6	5	8	8	7
Total Score	*60*	*56*	*56*	*56*	*50*

Arguments in favour of selecting the RCP x SSP scenarios:

- **Only RCP x SSP scenarios are sufficiently recent**. All of the global scenarios sets that were included in the evaluation, except for the RCP x SSP scenarios, are not very recent. As most were developed about 10-15 years ago, this also explains why there was a need for a new set of global scenarios. It is a strong argument against using any other set of scenarios.
- **Only RCP x SSP has a time horizon of 2100**. Most of the global scenarios have a time horizon that is (much) shorter than 2100, although the IPCC SRES scenarios do extend until the end of the century.
- **RCP x SSP is most relevant for high-end climate scenarios.** Particularly the MA and the GEO-3/4 scenarios do not focus on climate change. A possible exception is the SRES A1FI scenario that is comparable to RCP8.5.
- **RCP x SSP is a set of global scenarios that should replace the IPCC SRES scenarios.** The previous points indicate that the IPCC SRES scenarios are most likely the second best choice. Yet, the RCP x SSP scenarios will replace the SRES scenarios as the new IPCC standard.

The main argument against the selection is:

- **The RCP x SSP scenarios are under development**. Using very recent scenarios comes at a price. As can be seen in Table 2.1, scores for several criteria are lower than for other scenario sets because of its recent completion (e.g. specificity for Europe; degree of quantification; acceptance by scientists). It is expected that this will improve over the course of IMPRESSIONS.

In short, although using a very recent set of scenarios comes with the risk of using products that might not live up to expectations, the RCP x SSP set is the only sufficiently recent set of global scenarios that extend until 2100, that are directly related to climate change, and that offer socio-economic scenarios of sufficient detail.

2.2. An introduction to the process of developing the RCP x SSP scenarios

A process is under way in the climate change research community to develop a new set of integrated scenarios, the RCP x SSP scenarios, describing future climate, societal, and environmental change (Moss et al., 2010; see Figure 2.1). This process started with the development of representative concentration pathways (RCPs) that describe a set of alternative trajectories for atmospheric concentrations of key greenhouse gases (Van Vuuren et al., 2011). Based on these, climate modellers produced a number of simulations of possible future climates over the 21st century (Taylor et al., 2012). In parallel, other researchers are producing a new set of alternative pathways of future societal development, described as shared socio-economic pathways (SSPs), and using integrated assessment models (IAMs) to produce additional quantitative elements based on them, including future emissions and land use change. A conceptual framework has been produced for the development of SSPs (O'Neill et al., 2014) and for how to combine IAM scenarios based on them with future climate change outcomes and climate policy assumptions to produce integrated scenarios (Ebi et al., 2014; Kriegler et al., 2014) and support other kinds of integrated climate change analysis.

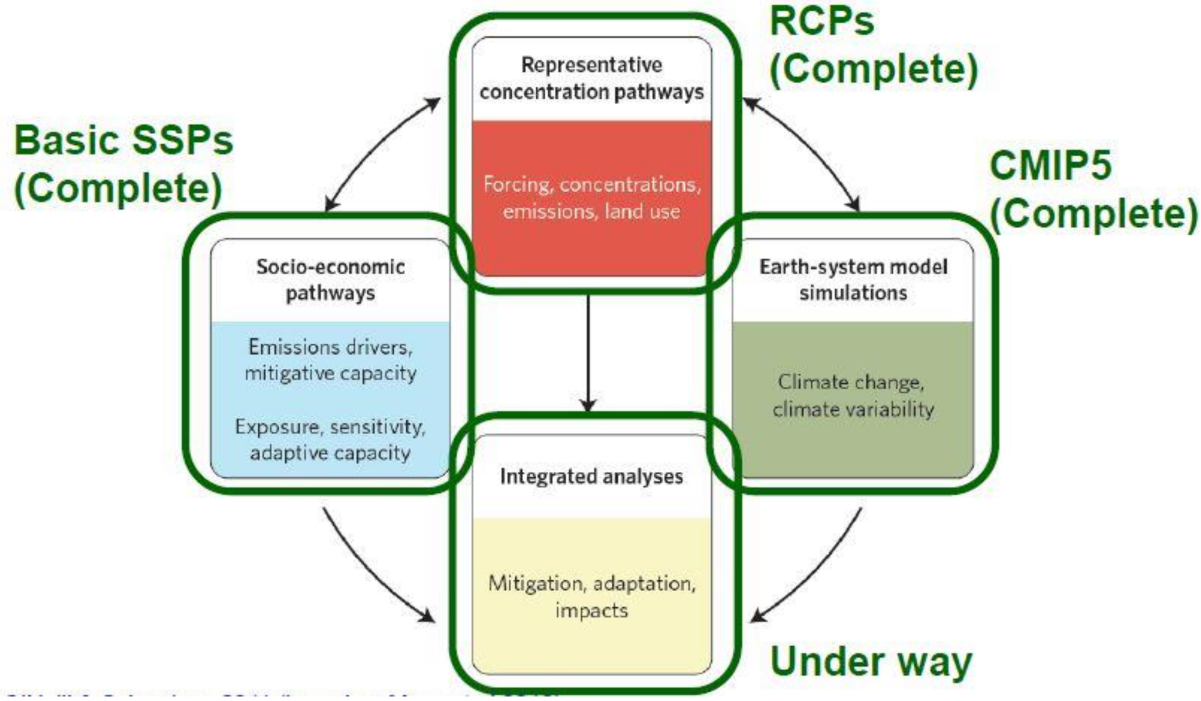


Figure 2.1: Framework of the new integrated global scenarios. Text in green indicates progress by the end of 2014. Source: O'Neill and Schweizer (2011).

As is clear from Figure 2.1, the "parallel process" as proposed and executed to develop the global scenarios is highly compartmentalised. Table 2.2 shows the basic lay-out of the compartments and how they can be assembled to develop "integrated scenarios": The **rows** represent four RCPs that correspond to certain greenhouse gas concentration developments. These are being used by the climate modelling community to link them to certain ranges of temperature, precipitation and sea level. As such, the rows represent the biophysical system dynamics and the effects on climate change. The **columns** represent five SSPs that correspond with distinct paths of development of the socio-economic system, focusing on mitigation and adaptation potential. The SSPs do *not* include adaptation/mitigation options or climate policies. Finally, the **cells** are the integrated scenarios where assumptions on climate, the socio-economic system and adaptation, mitigation and climate policies come together. Note that this approach assumes that RCPS and SSPs can be developed independently, while shared climate policy assumptions (SPAs) will always be in response to both a certain RCP and a certain SSP. Figure 2.1 indicates how, with the completion of RCPs, SSPs and earth system model runs, the scientific community is now facing the challenge of how to integrate the separately developed products over a range of scales to assess climate change impacts, vulnerability, adaptation and mitigation.

Table 2.2: Scenario development approach showing the connection between RCPs, SSPs and SPAs in the new global scenarios.

RCP (W/m^2)	SSPs				
	SSP1	SSP2	SSP3	SSP4	SSP5
2.6					
4.5	SPA				
6.0					
8.5					

2.3. Selection of RCP and SSP combinations

Here we briefly describe the reasoning for the selection of a set of RCP x SSP scenario combinations to be used in IMPRESSIONS. More details on the RCPs and SSPs are provided in Chapters 3 and 4, respectively, and on the integration of the RCPs and SSPs in Chapter 5.

2.3.1. Selection of RCPs and SSPs

There are four RCPs that cover a very large range of possible greenhouse gas concentration trajectories, ranging from +2.6 to +8.5 W/m^2 (values in the year 2100 relative to pre-industrial values). Given that the overall aim of IMPRESSIONS is to study the impacts of high-end scenarios, it was decided to select RCP8.5 and RCP4.5. These two RCPs ensure that:

- The broad range of mean temperature changes (2-6 degree Celsius) is considered;
- High-end climate change scenarios are included; and
- Lower-end climate change scenarios are not excluded, to enable comparison with high-end changes.

There are five SSPs that were chosen to cover the range of uncertainties related to challenges to mitigation and challenges to adaptation. Early in IMPRESSIONS, the decision was taken to limit the number of SSPs to be used in the participatory process to four, which is the recommended number of scenarios in a participatory scenario development process. It was decided to select SSP1, SSP3, SSP4 and SSP5 for a variety of reasons:

- These four SSPs capture the extremes of different socio-economic development pathways;
- SSP2 is intermediate between these four SSPs and is the most ‘moderate’ scenario;
- SSP2 has no equivalent in many other scenario datasets, particularly the CLIMSAVE scenarios.

2.3.2. Selection of RCP x SSP combinations

Out of the eight possible combinations between two RCPs and four SSPs, five combinations were proposed as a minimum set to be used in the IMPRESSIONS case studies (see Table 2.3). This links the SSPs with low mitigation challenges (SSP1/4) to RCP4.5 and those with high mitigation challenges (SSP3/5) to RCP8.5. We also assume that SSP3 matches reasonably well to both RCPs, enabling the effect of a different RCP, under the same SSP, to be analysed. Furthermore, both low adaptation challenges (SSP1/5) and high adaptation challenges (SSP3/4) are confronted with both RCPs. By having a certain amount of flexibility to vary the amount and type of climate change within an RCP, we keep options open to further discuss the exact nature of the combinations as work progresses.

Table 2.3: Selected RCP x SSP combinations and their characteristics.

	Low adaptation challenges	High adaptation challenges
High mitigation challenges	RCP8.5 x SSP5	RCP8.5 x SSP3
Low mitigation challenges	RCP4.5 x SSP1	RCP4.5 x SSP4 RCP4.5 x SSP3

3. Climate scenarios

3.1. Introduction

> **Climate scenario:** A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate. [Annex III; Glossary; IPCC 2013]

The use of climate scenarios in IMPRESSIONS is directed towards the needs of the impacts modelling activities in WP3. These include a wide range of models, including specialised local and sectoral models, agent-based models and broader scale Integrated Assessment Models (IAMs). Ideally, the details of the climate scenarios used within IMPRESSIONS across all regions, sectors and scales should span a consistent uncertainty range and build on the same general approaches when it comes to representing and assessing various sources of uncertainties. This section summarises some of the most commonly used climate model datasets and how we propose to utilise them consistently across tasks within IMPRESSIONS.

Our understanding of the sources and means of characterising uncertainties in long-term projections of climate change has not changed significantly over the last 10 years, but new experiments and studies have continued to work towards an incrementally more complete and rigorous quantification. The three main sources of uncertainty are model structural and parametric choices, future forcing scenarios and the internal variability of the system (both the real system and its representation through models). For long-term, multi-decadal and large-scale projections, the prevalent sources are the first two, but natural variability remains important for regionally detailed future changes, especially for variables other than temperature and aspects of climate change other than changes in means (e.g. characterisation of changes in some extremes). Improved methods to quantify model robustness show that lack of agreement across models on local trends is often a result of natural variability, rather than models actually disagreeing on their forced response. Model agreement depends on the variable and spatial and temporal averaging, with better agreement for larger scales. Agreement and thus confidence in projections is higher for temperature related quantities than for those related to the water cycle or circulation. The RCP-based experiments run with new climate models collected as part of phase 5 of the Coupled Model Intercomparison Project

(CMIP5; Taylor et al., 2012), available for the IPCC 5th Assessment Report (AR5; IPCC, 2013), form the most recent coordinated effort to portray climate scenario uncertainties based on models.

Regional climate scale information can be extracted from the CMIP5 models. However, many important features concern finer scales than those that are resolved well in this type of model. This has led to the development and use of different regional downscaling methods. The most notable of such methodologies are statistical downscaling and dynamical downscaling (a.k.a. regional climate modelling). Regional climate downscaling (RCD) techniques, including both dynamical and statistical approaches, are being increasingly used to provide higher-resolution climate information than is available directly from contemporary global climate models. The techniques available, their applications, and the community using them are broad and varied, and it is a growing area. It is important however that these techniques, and the results they produce, be applied appropriately and that their strengths and weaknesses are understood. This requires a better evaluation and quantification of the performance of the different techniques for application to specific problems. Building on experience gained in the global modelling community, a coordinated, international effort to objectively assess and inter-compare various RCD techniques provides a means to evaluate their performance, to illustrate benefits and shortcomings of different approaches, and to produce a more solid scientific basis for impact assessments and other uses of downscaled climate information. The World Climate Research Program (WCRP) has taken the lead in engaging a broader community of climate scientists in RCD activities. The Coordinated Regional Climate Downscaling Experiment (CORDEX) has served as a catalyst to achieve this goal.

3.2. Global and regional scenarios

Many new models may be classed as Earth Systems Models (ESMs), broadly meaning that they have an interactive carbon cycle component. Others, without such feedbacks included, are described as Atmosphere-Ocean General Circulation Models (AOGCMs). There is a much more comprehensive experimental design in CMIP5 than CMIP3 (Meehl et al., 2007; available for the IPCC 4th Assessment Report, IPCC, 2007), permitting more consistent diagnosis of model-dependent ranges in forcing, climate sensitivity and feedbacks. The number of participating models is roughly double compared to CMIP3. The CMIP5 co-ordinated experiment sees a marked increase in the number of ESMs compared with CMIP3. There is also a general increase in the number of forcing agents represented (in terms of types of aerosols and land use particularly), and black carbon aerosol is now a commonly included forcing agent, although nitrate aerosol is still not common.

Both “concentrations-driven” projections (for both AOGCMs and ESMs) and “emissions-driven” projections (for ESMs) were assessed from CMIP5 for AR5, the former allowing projections from the two classes of model to be combined on a more equal footing in assessing response uncertainties, and the latter (along with additional experiments within CMIP5) allowing climate-carbon cycle interactions to be explored more fully. The RCP scenarios, with internally consistent emissions and socio-economic storylines, are used as the basis for the forcing inputs to complex model projections. The closest correspondence between the RCPs and SRES for total Long Lived Greenhouse Gas forcing is between SRES B1 and RCP4.5. The RCP scenarios explore a broader range of radiative forcing through the 21st century than the SRES scenarios used for AR4. In particular, at the low end, the RCP2.6 radiative forcing (RF) is about 40% lower than SRES B1, the lowest SRES scenario used for AR4. The RCPs are referred to as pathways in order to emphasise that they are not definitive scenarios, but instead internally consistent sets of time-dependent future forcing projections that could potentially be realised, in fact with more than one underlying socio-economic scenario. They are representative in that they are one of several different scenarios, sampling the full range of published scenarios (including mitigation scenarios) at the time they were defined, which have similar RF and emissions characteristics. They are identified by the approximate value of the RF (in

W/m^2) at 2100 or at stabilisation after 2100 in their extensions, relative to pre-industrial defined at about 1765 (Moss et al., 2008; Meinshausen et al., 2011). RCP2.6 (the lowest of the four, also referred to as RCP3-PD) peaks at 3.0 W/m^2 and then declines to 2.6 W/m^2 in 2100, RCP4.5 (medium-low) and RCP6.0 (medium-high) stabilise after 2100 at 4.2 and 6.0 W/m^2 respectively, while RCP8.5 (highest) reaches 8.3 W W/m^2 in 2100 on a rising trajectory (see also Collins et al., 2013). The primary objective of these scenarios is to provide all the input variables necessary to run comprehensive climate models in order to reach a target RF. These scenarios were developed using IAMs that provide the time evolution of a large ensemble of anthropogenic forcings (concentration and emission of gas and aerosols, land use changes, etc.) and their individual RF values (Moss et al., 2008, 2010; van Vuuren et al., 2011). Collins et al. (2013) make it clear that due to the substantial uncertainties in RF, these forcing values should be understood as comparative 'labels', not as exact definitions of the forcing that is effective in climate models. This is because concentrations or emissions, rather than the RF itself, are prescribed in the CMIP5 climate model runs.

In AR5, regional projections of future temperature and precipitation patterns from AOGCMs and ESMs were comprehensively assessed and presented in an accompanying Atlas (Annex I; IPCC, 2013) and summarised in Chapter 14 (Christensen et al., 2013). The underlying assumption behind the assessment was that if the CMIP5 model spread represents projection uncertainty, the multi-model set can be used to provide estimates of an upper quantile, median value and a lower quantile (see e.g. Annex I; IPCC, 2013) of the projected climate change. However, taking this approach for various climate parameters independently will tend to decouple internal physical consistencies and even inflate the model uncertainty regionally, reflecting ongoing IMPRESSIONS work (see Madsen et al., 2015).

For instance, combining the 90th percentile winter temperature change with the 90th percentile winter precipitation change may not provide a physically consistent scenario because changes in the two variables are often related and cannot be regarded as independent. Therefore, using climate variables from individual models is recommended when applying more advanced impact models to assess consequences of climate change. In CMIP5 the total number of models that can be used is impressive: 32 (RCP2.6), 42 (RCP4.5), 25 (RCP6.0) and 39 (RCP8.5), respectively.

In Figure 3.1 the temporal evolution in global annual mean temperature for 38 CMIP5 members for the RCP8.5 scenario are shown; nine of these are continued until 2300; the remaining simulations end in 2100. Of the 29 GCM simulations that end in 2100, compared to the pre-industrial level (here defined as 1881-1910), five reach 6 degrees before or in 2100, and of the nine simulations that continue until 2300, another eight reach 6 degrees. In general the paths of global temperature change indicated by GCMs are quite different, with changes towards 2300 ranging between 5.5°C and 15°C global warming compared to pre-industrial temperature. The earliest time at which any model reaches 6 degrees is 2095. In order to explore the high-end scenarios it becomes necessary to concentrate on models with high climate sensitivity; those models reaching 6 degree before or just around 2100 are particularly relevant. In Annex A we show the geographical temperature and precipitation response from this set of models for both RCP8.5 and RCP4.5. The models are ordered according to their climate sensitivity.

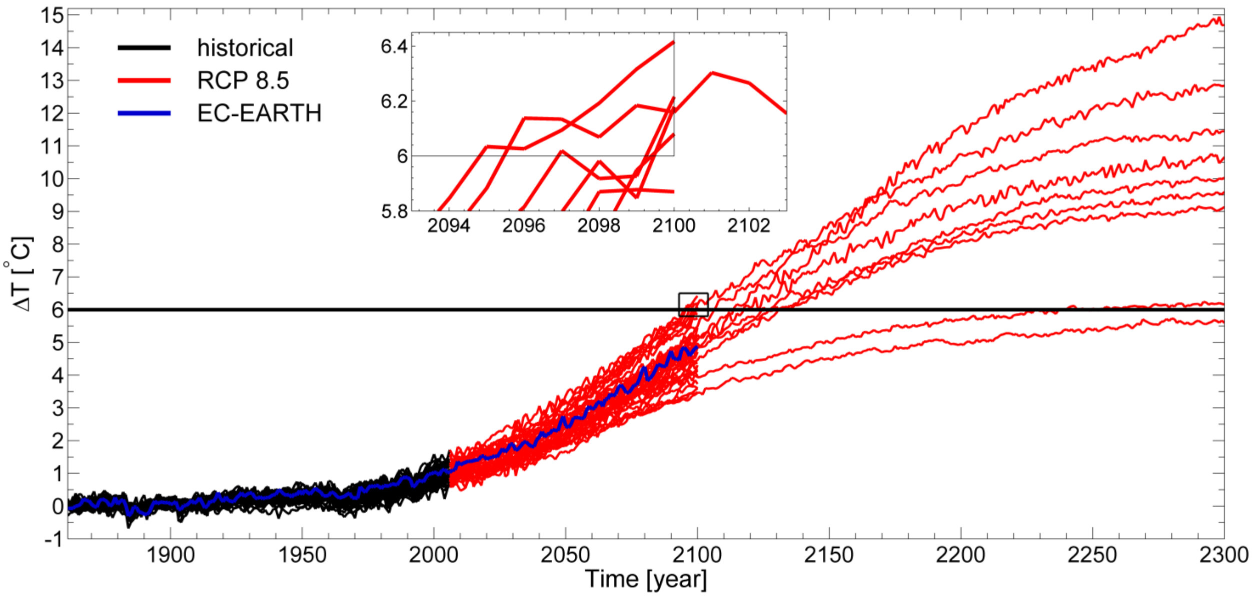


Figure 3.1: The global annual mean temperature for the RCP8.5 scenario of the 38 CMIP5 members compared to the pre-industrial level from 1881-1910. 29 simulations end in 2100, nine are continued to 2300. Judging from the figure the nine long simulations represent the full ensemble nicely, with members of both high and low climate sensitivity (Christensen et al. 2015).

In order to benefit from higher resolution databases both from observations and from models, the CORDEX archive has been inspected with the aim of identifying those CMIP5 models that have been dynamically downscaled over Europe. Figure 3.2 shows the European domain and topography used in CORDEX at the standard resolution of 50 km. This is the database we propose as the baseline for IMPRESSIONS.

In Annex A the full set of CORDEX experiments that has been made for RCP8.5 and RCP4.5 are displayed. The patterns of annual and seasonal mean changes of temperature and precipitation are shown. In order to use globally consistent datasets, it is emphasised here, that one constraint on the GCM options to choose is that an RCM/GCM combination with the GCM of concern is represented in the standard Euro-CORDEX set-up. Although CORDEX is a developing database, this constraint is furthermore given by what is available at the time of writing this report. Presented in the Annex is therefore what can be extracted by ultimo March 2015.

Besides the European case study, scenarios are required for four other regions: central Asia, Scotland, Iberia and Hungary. Central Asia is one of the CORDEX regions, but so far no RCM simulations are available for this region. For Scotland, the UKCP09 probabilistic scenarios are available and were used in the CLIMSAVE project. However, these simulations are not available for the RCP emission scenarios and it is important that the Scottish scenarios are prepared using a similar approach to the other local case study scenarios.

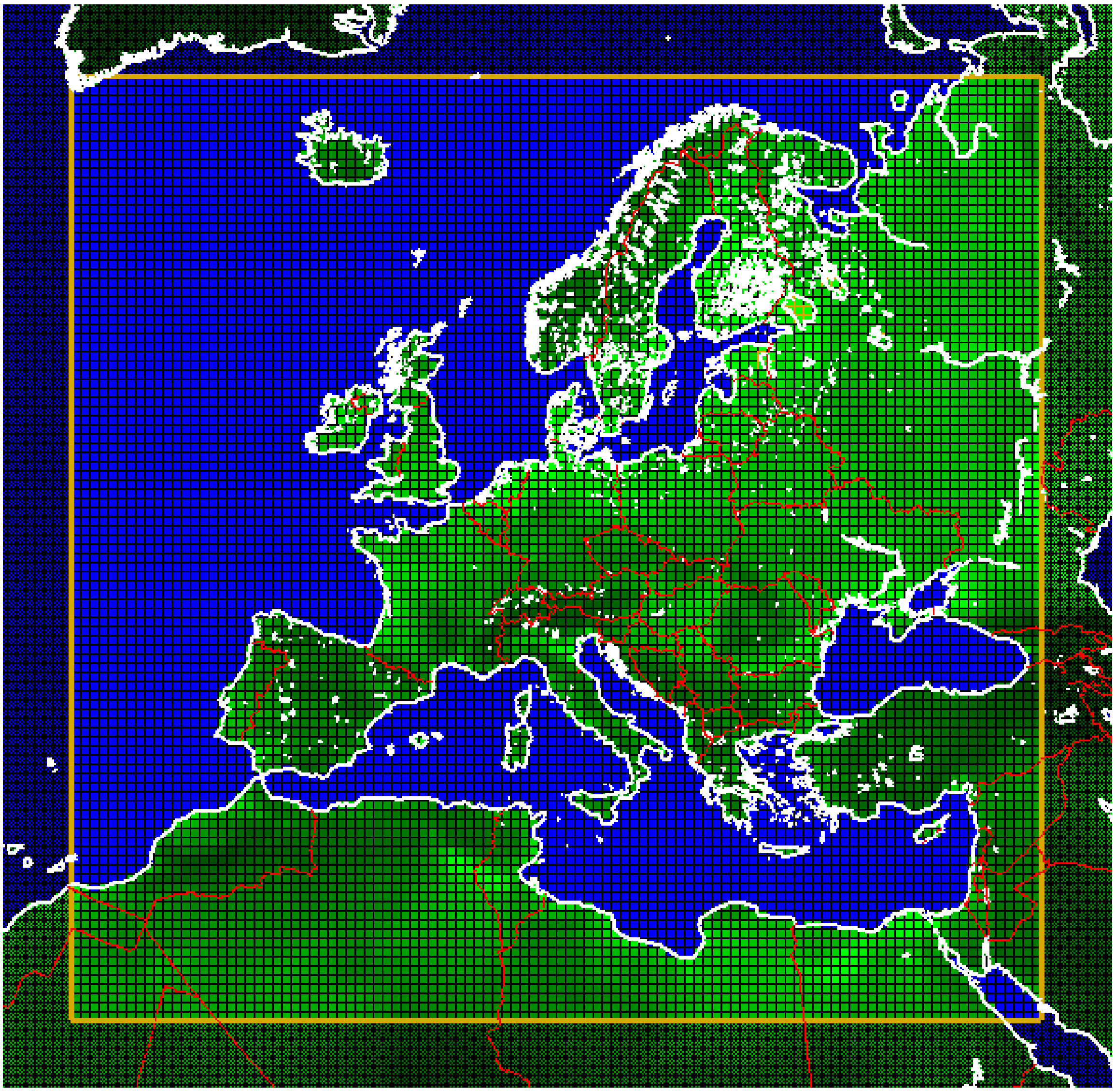


Figure 3.2: Region 4, EURO-CORDEX domain [http://wcrp-cordex.ipsl.jussieu.fr/index.php/community/domain-euro-cordex].

3.2.1. Criteria for selecting a subset of RCM/GCM from Euro-CORDEX

With the often limited computational resources available for comprehensive impacts modelling, schemes that in some way represent the model spread and portray mean behaviour are often used. This was even the case using data from CMIP3, where the total number of models is substantially lower.

A selection criterion for selecting representative models is difficult to construct in an objective manner. This always tends to depend on some elements of subjectivity. One perhaps more implicit subjectivity element is the tendency to look for the models that behave most realistically in the region of interest. This, however, is problematic in many ways. The most important caveat comes from the fact that while seemingly a necessary condition, this criterion is not a sufficient one. One can easily imagine a model with a reasonable representation of present day climate conditions that has a very dubious response to the radiative forcings leading to a different climate state. A very poor representation of the climate state elsewhere (e.g. wrong sea ice distribution, snow coverage in Eurasia, poor representation of ENSO) would cast doubt on the projections in the region of concern for example. Moreover, using different models for different regions will clearly not allow for a comprehensive comparison of the inter-regional changes. This is even problematic in the ways the AR5 presents the projected changes in the Atlas in AR5 (Madsen et al., 2015).

Many methods to select a sub-set of models have been proposed. In the ENSEMBLES project (van der Linden and Mitchell, 2009) it was recommended to use the full suite of models as no particular metric could be defined that would be able to discriminate clearly between poor performance and good performance across many aspects of performance indicators (Christensen et al. 2010). In the CLIMSAVE project (Harrison et al., 2015) a different approach was taken and a method that focused on the regional performance of CMIP3 models was chosen (Dubrovsky et al., 2015). Here, two methodologies were developed for identifying a representative subset of GCMs for use in climate change impact studies. One candidate subset was selected using expert judgment, whilst two other subsets were selected based on quantitative criteria: GCMs performance in reproducing the reference seasonal cycle of temperature and precipitation, and an ability of the subset to represent future inter-GCM variability. The three candidate subsets were validated and mutually compared in terms of changes in climatic characteristics (direct validation) and changes in impact indices (indirect validation). The results of the direct validation tests, which focused on an ability of the subsets to reproduce the multi-GCM variability (represented by the means and standard deviation) of changes in seasonal means of precipitation and temperature indicated one of the objective criteria based subset to be the best choice. The performance of this subset, which produced slightly better results than the other two subsets, is balanced between regions, seasons, climate variables (ΔTAVG and ΔPREC) and statistics (multi-GCM means and standard deviation). However, the results also show that the ranking of the three candidate subsets differs between climatic characteristics, seasons and region, so that the suitability of a given subset for a specific impact study would depend on the choice of the target region and the roles of individual seasons and/or climatic variables on the processes being studied. Furthermore, to account for multiple uncertainties, as well as providing GCM-based climate change scenarios for those GCM-emissions combinations not available in the source GCM database, the climate change scenarios for the CLIMSAVE project were determined using a pattern scaling approach (Santer et al. 1990; Mitchell 2003), in which the scenario is defined as the product of a standardised scenario and a change in global mean temperature, ΔT_G.

While both the ENSEMBLES and CLIMSAVE approaches present interesting, but different approaches to climate scenario selection, neither is particularly suitable for IMPRESSIONS as we need to limit the number of scenarios to a workable pragmatic set for the impacts work, but at the same time we want the impacts work to be comparable across the IMPRESSIONS regional case studies so we do not want to use a methodology based on a regional performance metric. Furthermore, the IMPRESSIONS selection criteria need to pay special attention to high-end scenarios rather than portraying uncertainty across all possible scenarios.

As can be deduced from Annex A, the number of available GCM/RCM combinations still represents an unmanageable number for many downstream impacts modelling applications. Therefore, there is a further need to select a more limited subset of the CORDEX experiments. In order to portray the full range of model climate sensitivity as far as possible and at the same time represent changes in global mean temperature from approximately 2 degrees to over 4 degrees, three GCM/RCM combinations with high climate sensitivity have been suggested for RCP8.5 and two GCM/RCMs with a low sensitivity have been suggested for RCP4.5. For the intermediate range, we suggest to use a combination of one high-end GCM/RCM for RCP4.5 and one low-end GCM/RCM for RCP8.5. In case only the high-end scenarios are to be considered, the two low sensitivity RCP4.5 GCM/RCM combinations may not be needed.

3.2.2. Observed data, the delta change approach and need for bias-correction

Climate models are not perfect and model simulations for the historical period often show systematic deviations when compared with observations. Impact models are most often calibrated against observed data and need baseline climate input with similar statistical properties if the predicted impacts are to be comparable with observed impacts. Also, future impacts related to the exceedance of a given threshold would have the wrong timing if the temperature of the baseline period was not adjusted to match observations. Therefore, statistical bias correction methods are most often applied to correct the climate model data for systematic deviations between observations and the historical simulation (Hempel et al. 2013). Delta change and bias-correction methods are the most common statistical approaches. In the traditional delta change approach, the observed data is used as the baseline which is combined with the simulated mean change to produce the climate scenarios. This method does not include changes in variability, but more advanced delta change methods have been developed as well (e.g. Räty et al. 2014). In bias-correcting methods, the observed and modelled baselines are compared and the modelled baseline is adjusted to get the same statistical properties as the observed baseline. The same adjustment is then applied for future scenario periods, assuming that the bias will not change in the future. Since the bias-correction is most often performed separately for each variable, the physical consistency of different climate variables may be destroyed. For regional studies, the biases may be reduced by regional downscaling which therefore may improve the consistency among variables. As for the delta change approach, a large number of bias correction methods are available (Hempel et al. 2013).

The climate scenarios in IMPRESSIONS rely on the availability of global observational data for the baseline period. The data sets should have high spatial and temporal resolution and include the relevant variables. Observational data from the Climatic Research Unit (CRU) were used in CLIMSAVE. These are global gridded monthly mean time-series data available at 0.5° resolution for all land areas and as country means (CRU TS v. 3.22 available for 1901-2013). The main variables included are mean temperature, diurnal temperature range, precipitation, wet-day frequency, vapour pressure and cloud cover. Max/min temperature, frost day frequency and potential evapotranspiration have been derived using simple relationships (Harris et al. 2014). In the European case study of CLIMSAVE, a high-resolution (10'x10') climatology of mean monthly surface climate for 1961-1990 was used (CRU CL 2.0, New et al., 2002). The climatology includes precipitation, wet-day frequency, mean temperature, diurnal temperature range, relative humidity, sunshine duration, ground frost frequency and wind speed. For use in the CLIMSAVE impacts modelling, min/max temperature was estimated from the diurnal temperature range and solar radiation was estimated from sunshine duration. As the European case study in IMPRESSIONS builds on the CLIMSAVE Integrated Assessment Platform (IAP), a dataset with a similar resolution for Europe has been requested for an updated baseline period (1981-2010).

However, in IMPRESSIONS we also need daily data for the local, regional and global case studies. Global data sets with sub-daily resolution are often based on reanalysis data that have been corrected against observed data. For example, the AIM Health model has used NCC data (Ngo-Duc et al., 2005) based on NCEP/NCAR reanalysis and available for 1948-2000, and the SWIM model has used the WATCH Forcing Data (WATCH WFD, Weedon et al., 2011) which were also used for calibration of the model. The WATCH WFD data were prepared in the WATCH EU FP6 project for use in hydrological models and is based on ERA-40 reanalysis data with monthly averages being bias-corrected against CRU observational data (CRU TS2.1). It has a 0.5^{o} horizontal resolution and variables include 2m temperature, 10-m wind speed, 10-m surface pressure, 2-m specific humidity, downward radiative fluxes, rain- and snowfall. This dataset includes daily and 3-hourly data and is available for 1958-2001. None of these datasets are available for the entire IMPRESSIONS baseline period of 1981-2010 and we would need to consider more recent datasets if the baseline period is to be covered. A more recent alternative could be the WATCH WFDEI (Weedon et al., 2014) data which is using the same methodology as the WATCH WFD, but based on ERA-Interim reanalysis and available for 1979-2012. The data are bias-corrected against the CRU TS3.1 monthly mean data (similar to TS 3.22).

Bias-corrected daily data based on model output from global and regional models have been prepared in several projects. In the ISI-MIP project (Inter-sectoral Impact Model Intercomparison Project), for example, a large number of CMIP5 models have been bias-corrected against the WATCH WFD data using 1960-1999 as the baseline. In the CLIPC project, models from the CORDEX archive have been bias-corrected against the E-OBS European observational dataset (baseline 1981-2010). These bias-corrected data are or will be available for use in other projects. However, the different bias-corrected projections relate to a specific observational dataset and baseline period and will often be available for a limited sub-set of the available climate model projections. Also different bias-correction methods have been applied. In CLIMSAVE, a traditional delta change method was used to prepare European scenarios for the CLIMSAVE IAP. The scenarios were based on the CRU CL2.0 monthly mean baseline data (New et al., 2002) and change values for monthly mean temperature, precipitation and solar radiation were estimated from a selected sub-set of CMIP3 models. The coarse resolution change values were downscaled to the high-resolution 10' grid used in the impact models, assuming that changes in individual climate characteristics have much smaller spatial variability than the absolute baseline data (Dubrovsky et al., 2014).

3.2.3. Towards probabilistic climate scenarios

In the ENSEMBLES project, Déqué and Somot (2010) utilised the full suite of ENSEMBLES downscaled models to assess modelling uncertainty in a probabilistic sense. Fourteen RCMs were driven by GCMs to provide 17 fine-scale (25 km) climate change scenarios for the period 2021-2050. In a preliminary exercise, these RCMs were driven by gridded observations (ERA40 reanalysis) to simulate as accurately as possible the 1961-2000 period. The quality of this reproduction was used to calculate a weight for each model (Christensen et al. 2010). Each individual model climate had an uncertainty due to the finite sampling (30 yr). These spreads were combined by those weights to produce an ensemble uncertainty. The distribution obtained by ENSEMBLES weights was compared with a distribution using equal weights, distributions using random weights and distributions based on a single model. As far as the reproduction of the observed distribution (1961–1990) is concerned, there was no evidence that the ENSEMBLES weight system provides results closer to observation than equal weights or weights drawn at random. A single model taken at random yields a quality score not better than ENSEMBLES in the case of precipitation, and worse than ENSEMBLES in the case of temperature. As far as climate change for 2021-2050 is concerned, the use of ENSEMBLES weights instead of equal weights also led to a similar response at daily as well as 30 yr mean time scales.

In order to address the IMPRESSIONS need for a probabilistic approach; further efforts will be made to address the spread in climate scenarios, both global and regionally downscaled. The work initiated in Madsen et al. (2015) will be put forward as a basic and new approach, but further discussions within IMPRESSIONS is needed to understand how these ideas might be used. This will be initiated during 2015 so that decisions are made within the scenario group before the General Assembly meeting in January 2016.

3.2.4. Links with the HELIX and RISES-AM projects

IMPRESSIONS is one of three funded FP7 projects under Theme ENV.2013.6.1-3: Impacts of higher-end scenarios (global average warming > 2 °C with respect to pre-industrial level). The two others are HELIX (http://helixclimate.eu/; led by Richard Betts, University of Exeter) and RISES-AM (http://risesam.eu/; led by Prof Agustin Sanchez-Arcilla, University of Catalonia). The three projects are working together on defining comparable approaches to identify the high-end scenarios that will be assessed in order to avoid parallel developments and instead foster synergies. HELIX and IMPRESSIONS in particular are working together on providing and underpinning the science behind selection criteria for choosing climate models or their results for use in the impact, vulnerability and adaptation WPs within all three projects. Members of the scenario team are coordinating their activities through regular telecons and occasional face-to-face meetings.

In IMPRESSIONS, the main climate scenarios will be derived from those climate model runs available through CMIP5 (not CMIP3 as CMIP5 captures an appropriate range), emphasising RCP8.5, but also RCP4.5. In HELIX the climate scenarios to be considered are being defined by addressing the global temperature thresholds 2°C, 4°C and 6°C, focusing on time of emergence. This requires different time windows to be chosen for different models as proposed in Vautard et al. (2014). Again CMIP5 is central, but also the perturbed physics ensemble (PPE) available from the Hadley Centre is being considered. IMPRESSIONS may choose to consider this approach as well at a later stage. Details on the scenario interaction between the three FP7 projects can be found in the IMPRESSIONS Scenario Methodology living document (Kok and Christensen, 2014).

3.3. Recommendations and workplan

3.3.1. RCP and climate model selection

The parallel development of the RCPs and SSPs implies that when choosing to work with specific SSPs, the need for choosing RCPs should also be considered. IMPRESSIONS deals with high-end scenarios; therefore, it is not considered useful to use climate scenarios with a global mean temperature response below 2 degrees, which by definition eliminates RCP2.6 as an option. There are also few downscaled climate projections available for Europe based on this forcing. However, a large number of model simulations are available from CMIP5 and CORDEX for the other scenarios (RCP4.5, RCP6.0 and RCP8.5) with global mean temperatures above 2 degrees. However, as previously mentioned, RCP6.0 is the poorest represented in terms of available model runs in the CMIP5 and hence the CORDEX archives (see also Figure 3.3). Nevertheless, amongst the CMIP5 models, the range in model climate sensitivity results in an overlap of the projected end of century global mean temperature, when comparing the model representing RCP8.5 with lowest climate sensitivity to the model representing RCP4.5 with the highest (see Figure 3.3; light blue and light red). It was therefore decided that in order to portray the model spread in global temperature, the focus in IMPRESSIONS should be on RCP4.5 and RCP8.5.

Since IMPRESSIONS aims at addressing impacts related to high-end climate change and also includes three local European case studies which rely on daily data we propose to use climate model sensitivity and the availability of regional model data as the main selection criteria. By inspection of Annex A, we find that for three of the eight GCMs with a global mean temperature change above 4 degrees for RCP8.5 (2071-2100 vs. 1981-2010), the GCM has been downscaled by at least one regional climate model and output is available in the CORDEX archive. These high-end GCMs are HadGEM2-ES, CanESM2 and IPSL-CM5A-MR for which the global temperature change is between 4.01 and 4.19 for RCP8.5. At the low end, MPI-ESM-LR and GFDL-ESM2M have a temperature increase of 1.46 and 1.07°C and we select these GCMs to represent low-end climate change. For the intermediate range, we suggest the low-end GCM GFDL-ESM2M for RCP8.5 and the high-end GCM HadGEM2-ES for RCP4.5 – these models project a very similar global mean temperature increase of 2.39 and 2.35°C, respectively. Note, that MPI-ESM-LR that is low-end for RCP4.5 is actually a mid-range GCM for RCP8.5 with a temperature increase of 3.22°C. Table 3.1 summarises the range of global mean temperature change for the selected GCMs along with the corresponding temperature changes projected for Europe in the available RCM simulations.

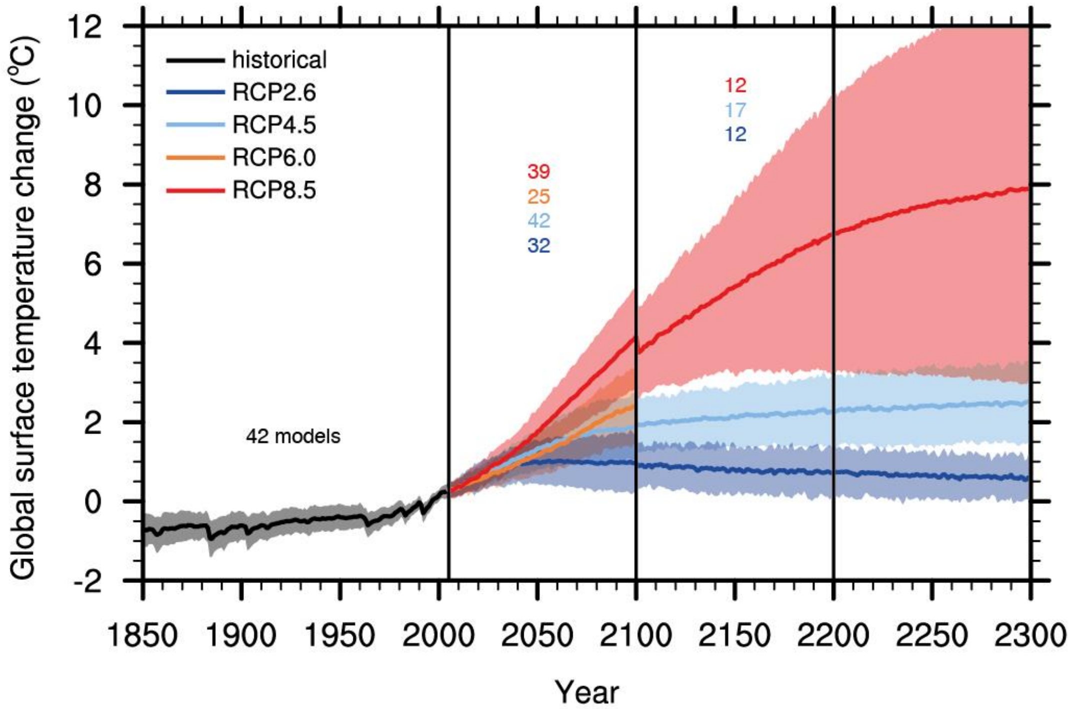


Figure 3.3: Time series of global annual mean surface air temperature anomalies (relative to 1986-2005) from CMIP5 RCP-driven experiments. Projections are shown for each RCP for the multi-model mean (solid lines) and the 5 to 95% range (±1.64 standard deviation) across the distribution of individual models (shading). [IPCC, 2013]

Table 3.1: The change in global mean temperature (2071-2100 vs. 2081-2010) for RCP8.5 and RCP4.5 for each of the five selected GCMs. For each GCM, the corresponding temperature change for the European domain is included for each available RCM simulation. The core set is indicated by numbers shown in red.

Selected GCM	Global ΔT		Selected RCM	Europe ΔT		Additional RCMs	Europe ΔT	
	RCP8.5	RCP4.5		RCP8.5	RCP4.5		RCP8.5	RCP4.5
HadGEM2-ES	4.19	2.35	RCA4	4.28	2.15	-	-	-
CanESM2	4.06	2.11	CanRCM4	4.26	2.44	RCA4	4.25	2.38
IPSL-CM5A-MR	4.01	2.05	WRF	4.02	2.34	RCA4	4.14	2.36
MPI-ESM-LR	3.22	1.46	CCLM4	3.07	1.42	RCA4	3.24	1.51
GFDL-ESM2M	2.39	1.07	RCA4	2.86	1.46	-	-	-

For CanESM2, two RCM realisations are available (CanRCM4 and RCA4) and it is obvious from Annex A that the precipitation patterns are quite different in the two downscaled simulations. RCA4 projects a significantly larger drying in southern Europe in summer than the CanRCM4 whereas CanRCM4 has a larger increase in Central European winter precipitation. To cover the widest range in response patterns, we have selected the model combinations that include the largest number of different RCMs.

To summarise, we suggest the following core set of GCM/RCMs for use in IMPRESSIONS:

- RCP8.5: HadGEM2-ES/RCA4, CanESM2/CanRCM4, IPSL-CM5A-MR/WRF and GFDL-ESM2M/RCA4;
- RCP4.5: GFDL-ESM2M/RCA4, MPI-ESM-LR/CCLM4 and HadGEM2-ES/RCA4.

With the chosen subset of seven (five if low-end is excluded), impacts models can in most cases make use of the full suite of models and in this way portray some aspects of the overall uncertainty space. To keep internal consistency within IMPRESSIONS pattern scaling based on the suggested subset of models could offer a way to further explore uncertainty space. Christensen et al. (2015) demonstrate that regional aspects of projected climate change could possibly be addressed using pattern scaling techniques based on model ensembles, even representing higher order statistics of climate parameters such as precipitation return periods. However, it seems that using the full set of available models from CMIP5 and CORDEX offers a more complete approach. How these procedures differ will be further explored within IMPRESSIONS to develop an extended set of climate projections that modellers can optionally apply to impact models in addition to the core set of seven GCMs/RCMs.

3.3.2. Observed data and bias-correction

In IMPRESSIONS, there is a need for gridded observationally based data for global, regional and local impact models, needing various variables at daily, monthly and annual time scales. As a main issue in IMPRESSIONS is to compare results across scales, it would be advantageous to use a common set of observed data that can be applied at all scales. Even though the individual impact models have quite different data needs, we would recommend using a common set of daily and monthly data throughout the project. The selection of a relevant common observation-based dataset is constrained by the very recent baseline period of 1981-2010 adopted in IMPRESSIONS and we therefore recommend using the WATCH WFDEI dataset since it covers the full baseline period at a sub-daily timescale and includes the relevant variables. We are aware that, in some cases, better datasets might exist for a local region or for the limited number of variables needed by a specific model. In these cases a comparison between the relevant datasets and an analysis of expected implications should be performed. This needs to be considered in more detail as IMPRESSIONS progresses. In particular, it would be useful to define guidelines and metrics that enable assessment of the consequences of using different datasets across the IMPRESSIONS impacts models, both in terms of the chosen baseline and the origin of the dataset. This could contribute to the uncertainty assessment described in Deliverable 3.1 (Section 5) by better understanding the effects of differences in the adopted baseline or calibration datasets on impact model outputs across scales and sectors.

For the European case study, which builds on the CLIMSAVE project, it was initially suggested to use the CRU monthly mean data. As the WATCH WFDEI are bias-corrected against CRU data, it has been discussed if the more well-known CRU data could still be recommended for the monthly mean data. However, differences exist for Tmin and Tmax which are not estimated using the same method so for consistency across the different case studies, we would recommend the use of the WATCH WFDEI data for both daily and monthly time scales. For the selected sub-set of GCM/RCMs, the traditional delta change method will be used to construct scenarios for the impact models that need monthly mean information, e.g. in the European case study. Bias-corrected projections will be provided for the models that need daily data.

4. Socio-economic scenarios

4.1. Introduction

Socio-economic scenarios are defined here as future outlooks of socio-economic developments, including changes in society, economic factors, governance, institutions, culture etc. Often, socio-economic scenarios consist of qualitative and quantitative components. Quantitative components provide common assumptions for elements such as population, economic growth, or rates of technological change that can be meaningfully quantified and that can serve as inputs to models. Qualitative narratives (or storylines) describe the evolution of aspects of society that are difficult to project quantitatively (such as the quality of institutions, political stability, environmental awareness, etc.) and provide a basis for further elaboration of the scenarios by users. Note that socio-economic scenarios mostly refer to projections or exploratory scenarios, thus excluding strategies, policies, and actions, such as adaptation and mitigation options.

This chapter describes the global SSPs in more detail and reports on the activities undertaken in the five case studies from IMPRESSIONS (Europe, Scotland, Iberia, Hungary, and central Asia – referred to as EU external) in relation to developing socio-economic scenarios, taking the global SSPs as a starting point.

4.2. The global SSPs

The text in this section is largely based on O'Neill et al. (2015), in which the SSPs are explained and documented. For more details we refer to that paper.

4.2.1. Concepts and underlying assumptions

The SSPs describe plausible alternative changes in aspects of society such as demographic, economic, technological, social, governance and environmental factors. They include both qualitative descriptions of broad trends in development over large world regions (narratives) as well as quantification of key variables that can serve as inputs to integrated assessment models, large-scale impact models and vulnerability assessments. A third element of the SSPs are tables that summarise trends in key elements of the SSPs.

Within the conceptual framework for integrated scenarios, the SSPs are designed to span a relevant range of uncertainty in societal futures. Unlike most global scenario exercises, the relevant uncertainty space that the SSPs span is defined primarily by the nature of the outcomes, rather than the inputs or elements that lead to these outcomes. As such, the design process begins with identifying a particular outcome and then identifies the key elements of society that could determine this outcome. Because climate change scenarios generally cover options to mitigate or adapt to climate change, the SSP outcomes are specific combinations of **socio-economic challenges to mitigation and socio-economic challenges to adaptation** (see Figure 4.1). That is, the SSPs are intended to describe worlds in which societal trends result in making mitigation of, or adaptation to, climate change harder or easier, without explicitly considering climate change itself. The framing of SSPs in terms of challenges facilitates research based on the SSPs that collectively can characterise a range of uncertainty in the mitigation required to achieve a given climate outcome, or the adaptation possibilities associated with that outcome. The SSPs are developed based on the best current hypotheses about which elements of societal development pathways are the most important determinants of these challenges.

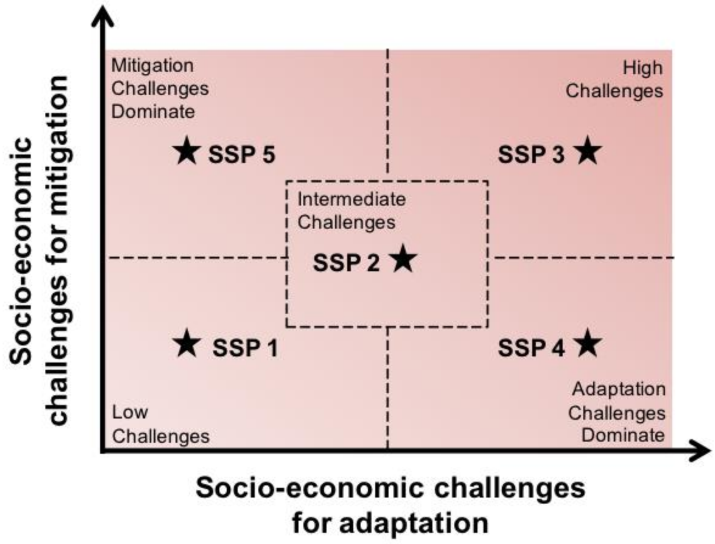


Figure 4.1: The five SSPs representing different combinations of challenges to mitigation and challenges to adaptation.

The general purpose of the SSPs is to provide broad descriptions of future conditions that are relevant for both the analysis of emissions drivers and mitigation strategies, and the analysis of societal vulnerability to climate change, climate impacts and potential adaptation measures. The narratives, therefore, convey a basic "storyline" that can guide the specification of further elements of the scenario, including quantitative elements such as population and economic growth patterns. The narrative of global development also guides regional and sectoral extensions of the scenarios, including the formulation of regional narratives that fit within the overall global picture. As a result, the SSPs are rather short and simple, certainly relative to much richer storylines that are used in decision-making contexts to illustrate the consequences of specific courses of action.

The current version of the SSPs is considered to be **"basic SSPs"**; that is, they contain enough information to sketch alternative development pathways that are plausible and that enable them to be located in a particular area of the challenges space. However, for many applications, **"extended SSPs"** are likely to be required, which would contain additional, more detailed information for particular regions, sectors, or variables or that would be enhanced according to specific needs.

4.2.2. Potential use of the SSPs

A close link exists between socio-economic challenges to mitigation and adaptation, and the dimensions of sustainability and development. As a result, the SSPs also cover a wide range of development and sustainability outcomes. Figure 4.2 illustrates the potential of the SSPs in relation to economic growth and societal sustainability. O'Neill et al. (2015) openly invite other research groups to use, explore, and extend the SSPs using other key elements than the socio-economic challenges to adaptation and mitigation: "Capturing lessons from experience gained in applying the SSPs to integrated climate change research, as well as in extending them to particular sectors and geographic scales, should be a high priority." The latter is exactly what is being attempted in IMPRESSIONS and what will be elaborated in the subsequent sections.

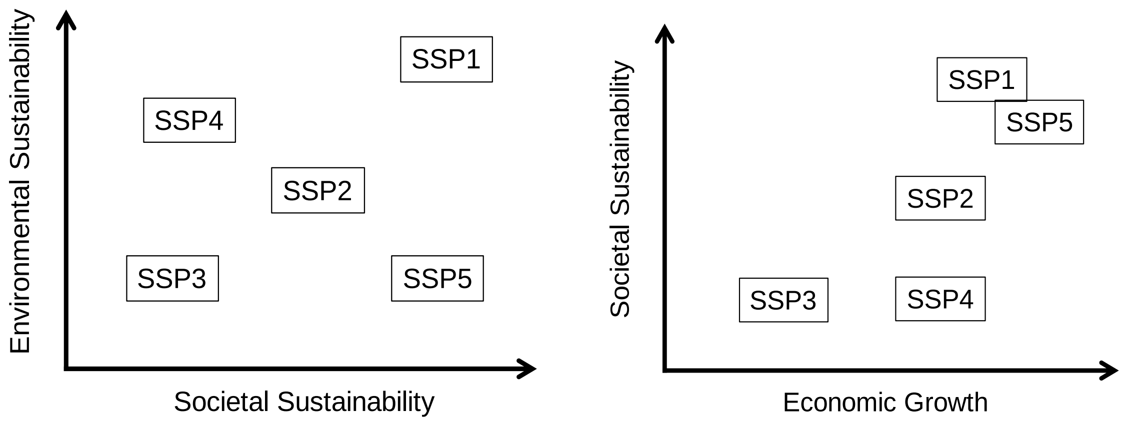


Figure 4.2: Illustrative mapping of SSPs to a space defined by elements of the SSP narratives as opposed to consequences of the narratives for challenges to mitigation and adaptation.

4.3. Extending the SSPs in IMPRESSIONS

4.3.1. Selection of set to be used in IMPRESSIONS

Early in the project, the decision was taken to limit the number of SSPs to be used in the participatory process to four. This had a number of reasons:

- Participatory processes usually limit the number of socio-economic scenarios that can be developed to four, which is in line with the "scenario axes approach" within which two main uncertainties provide the skeleton for four scenarios.
- An even number of scenarios is preferable as it avoids the risk of one being regarded as Business-As-Usual or "most likely".
- The ultimate aim to develop a (small) number of integrated scenarios by considering a small number of RCP x SSP combinations (see Section 2.3.2). Both the number of RCPs and SSPs needed, therefore, to be limited.

It was decided to exclude SSP2 from the set of socio-economic scenarios. The main reason was that it lacks an identity with most aspects changing "moderately". It would, therefore, be the most difficult scenario to quickly explain to stakeholders and thus also the most difficult scenario for stakeholders to extend to their region. The set of SSPs to be used in IMPRESSIONS is therefore SSP1, SSP3, SSP4, and SSP5. It was also decided to, where possible, refrain from using the term "SSP". When extending the SSPs as described in the O'Neill et al. (2015) paper, they are typified as socio-economic scenarios, which should not be characterised as "pathways". The latter term is confusing, particularly given the fact that pathways are collections of strategies and mitigation/adaptation options in the context of IMPRESSIONS (see WP4). Hence, in the remainder of this deliverable, we refer to the SSPs by their names as indicated in O'Neill et al. (2015).

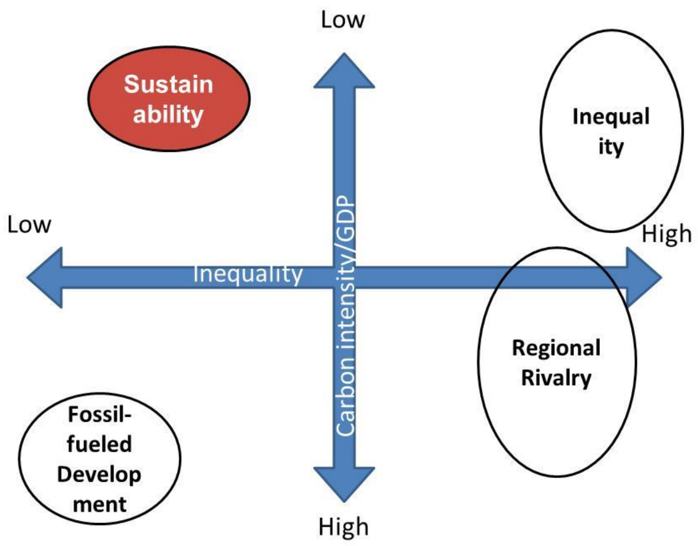
4.4. Summary overview of the global SSPs

This section provides an overview of the four SSPs being used in IMPRESSIONS in terms of a summary of the narrative, trend indications of key elements, and a graphical representation of the scenarios plotted in a diagram with two key uncertainties that were deemed most illustrative for the application and development in IMPRESSIONS (carbon intensity per unit of GDP and inequality). Full narratives of the SSPs can be found in Annex B.

4.4.1. SSP1: Sustainability – The Green Road

Within *Sustainability*, there is a high commitment to achieve development goals, to increase environmental awareness worldwide, and to gradually move toward less resource-intensive lifestyles. The world shifts gradually, but pervasively, toward a more sustainable path, emphasising more inclusive development, driven by increasing evidence of, and accounting for, the social, cultural, and economic costs of environmental degradation and inequality. The shift evolves over time, is not uniform, and is punctuated by periodic tragedies that bring these costs into stark relief. Over time, the initially disparate constituencies become mutually reinforcing, ultimately leading to effective and persistent collaboration. The world is further characterised by a combination of directed development of environmentally friendly technologies, a favourable outlook for renewable energy, institutions that can facilitate international cooperation, improved human well-being, and relatively low energy demand. Overall, it is a bumpy road, but one that eventually moves the world in a more sustainable direction.

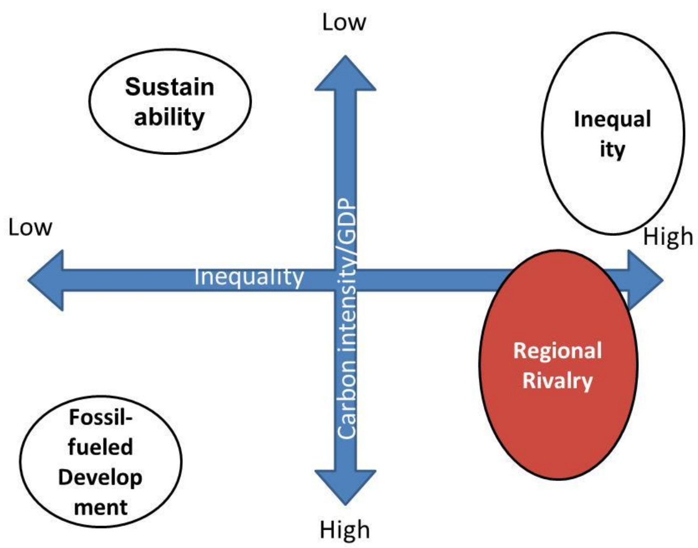
Key assumptions	**Sustainability – The Green Road**
Environmental policies	Improved management; strong regulations
Policy orientation	Towards sustainable development
Institutions	Effective
Education	High
Social cohesion & equity	High
Health investments	High
Inequality	Reduced across and within countries
Globalisation	Connected markets, local production
Consumption and diet	Low growth in material consumption, low meat diets
Population growth	Relatively low
Technology development & transfer	Rapid
Carbon (energy) intensity	Low
Environmental status	Improving conditions



4.4.2. SSP3: Regional Rivalry – A Rocky Road

Sparked by economic woes in major economies and regional conflict over territorial and national issues, antagonism between and within regional blocs increases. This causes a resurgent nationalism, concerns about competitiveness and security, and regional conflicts, which push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns. There are pockets of extreme poverty alongside pockets of moderate wealth, with many countries struggling to maintain living standards and provide access to safe water, improved sanitation, and health care for disadvantaged populations. The world is further characterised by growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change.

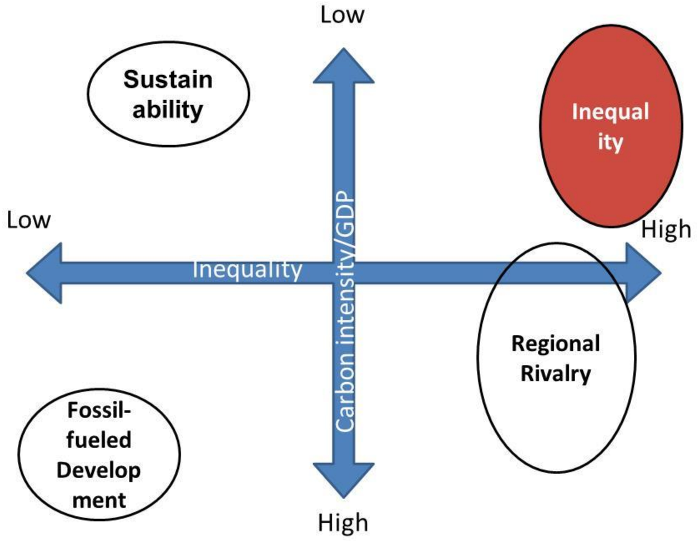
Key assumptions	Regional Rivalry – A Rocky Road
Environmental policies	Low priority for environmental issues
Policy orientation	Towards security
Institutions	Weak global; national governments dominate
Education	Low
Social cohesion & equity	Low
Health investments	Low
Inequality	High, especially across countries
Globalisation	De-globalising; regional security
Consumption and diet	Material-intensive consumption
Population growth	Low in OECD; High in high fertility countries
Technology development & transfer	Slow
Carbon (energy) intensity	High, particularly in regions with fossil fuel resources
Environmental status	Serious degradation



4.4.3. SSP4: Inequality – A Road Divided

Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labour intensive, low-tech economy. Power becomes more concentrated in a relatively small political and business elite, which is capable of acting quickly and decisively. At the same time, substantial proportions of populations have a low level of development and limited access to effective institutions for coping with economic or environmental stresses.

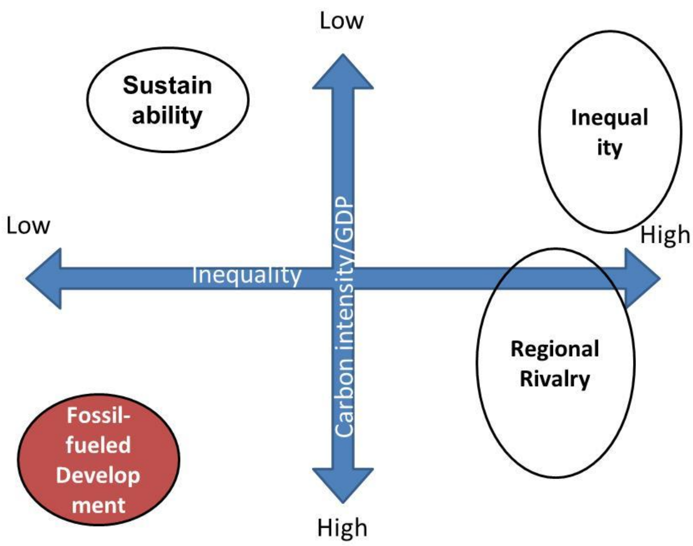
Key assumptions	**Inequality – A Road Divided**
Environmental policies	Focus on local environment in high-income countries; no attention to global issues
Policy orientation	Towards benefit of the political and business elite
Institutions	Effective for elite
Education	Very low to medium, very unequal
Social cohesion & equity	Low, stratified with medium equity
Health investments	Unequal within regions, lower in low income countries
Inequality	High, especially within countries
Globalisation	Globally connected elite
Consumption and diet	Elite: high/material; rest: low
Population growth	Low in OECD, relatively high elsewhere
Technology development & transfer	High in high-tech economies and sectors; slow in others with little transfer
Carbon (energy) intensity	Low/medium
Environmental status	Highly managed near high-income areas; degraded otherwise



4.4.4. SSP5: Fossil-fueled Development – Taking the Highway

Driven by the economic success of industrialised and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers. The push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles, linked to a strong faith in the ability to effectively manage social and ecological systems. The world is characterised by a strong reliance on fossil fuels but a total lack of global environmental concern.

Key assumptions	**Fossil-fueled Development – Taking the Highway**
Environmental policies	Focus on local environment, little concern with global issues
Policy orientation	Towards development and human capital with free markets
Institutions	Increasingly effective
Education	High
Social cohesion & equity	High
Health investments	High
Inequality	Strongly reduced, especially across countries
Globalisation	Strong and increasingly connected markets
Consumption and diet	Materialism, high consumption, meat-rich
Population growth	Relatively low
Technology development & transfer	Rapid
Carbon (energy) intensity	High
Environmental status	Highly engineered approaches



4.4.5. What makes the SSPs tick?

This section provides a preliminary analysis of the differences and similarities between the four different SSPs. It serves to facilitate the comparison between the global SSPs and their matching with existing scenarios at other scales (see Sections 4.5 and 4.6).

A first and most crucial observation is that there are two pairs of SSPs:

SSP1 and SSP5: The future outlook of both scenarios is, in essence, positive. Low population growth, high levels of education, equity and a sustained economic growth in an increasing globalisation world. In fact, the two narratives are similar in most other characteristics (technological change, institutions) as well. And indeed, together, those aspects results in both cases in futures where challenges to adaptation are low, for similar reasons. Yet, there are crucial differences. Perhaps most importantly, in SSP5 the focus is on improving of human capital, whereas in SSP1 natural capital comes first. In SSP5, quickly improving human well-being is (literally) fuelled by cheap fossil fuels, and without much attention for environmental degradation. Although the seeds are present, society in SSP5 does not transform to a low-input, low-output world which does results towards the end of SSP1.

SSP3 and SSP4: The future outlook of both scenarios is, in essence, negative, except for the upper class. For the vast lower class, population growth is high, education levels remain low, equity is low, as well as economic growth. Additionally, both scenarios assume slow technological development and high resulting environmental impacts. Consequently, both scenarios project high challenges for climate adaptation. However, there are crucial differences, mostly related to the degree to which societies become unequal. In SSP3, there is a growing gap between rich and poor, but without the rich being more than moderately wealthy and not well-connected. In SSP4, the gap between the poor masses and the global elite is huge, with the elite benefiting in every sense of the word, without sharing much with the rest of the population. This gives rise to fundamental differences between SSP3 and SSP4, in which it is assumed that there is an elite that is well organised, globally connected, and with access to new technologies and accompanying low energy intensity. Consequences also include less environmental impacts and a more diversified use of energy sources, as well as high urbanisation rates. Based on a similar starting point and similar initial trends, SSP3 and SSP4 partly develop to similar circumstances by 2100, but they are also very different in some respects, particularly related to challenges to mitigation.

In conclusion, SSP1 is a utopian, sustainable future; SSP3 is a dystopian, doom scenario. Both exist in many scenario sets and mirror in many ways earlier endeavours. In SSP4, a growing and powerful elite successfully escapes the misery; the scenario is a mix between elements of SSP1 (for the elite) and SSP3 (for the masses). In SSP5, trends mirror those in SSP1, but low priorities for environmental protection bend some trends in the direction of SSP3. The scenario is a mix between SSP1 (early stage) and some hints of SSP3 (later stage). As a result, drivers are unique sets for the four SSPs. Impacts, however, may be very similar for SSP1 and SSP5 (because of similarities early in the stories) and for SSP3 and SSP4 (because of similarities in how the masses are impacted).

4.4.6. Scenario archetypes – beyond the SSPs

Even though the RCP x SSP scenarios are singled out as the best set of scenarios to use as a starting point in IMPRESSIONS (see Section 2.1), this does not exclude the use of information from other scenario sets. There is a wealth of other sets of socio-economic scenarios available, and Sections 4.5 and 4.6 elaborate on the use of (or combination with) other scenario endeavours. More generally, however, several authors have attempted to classify the large number of different scenario sets into so called scenario archetypes. Rothman (2008) provides a good overview of a number of archetypes that in general agree with other studies (e.g. Busch, 2006; Zurek, 2006; Westhoek et al., 2006). These four archetypes correspond strongly to the four scenarios that most (global) scenario studies have developed – including to some extent the RCP x SSP scenarios. Figure 4.3 places some recent scenario studies on the two axes that represent the two main uncertainties that determine the main developments in the scenario archetypes. The first axis represents uncertainty about whether the world will further globalise, or whether globalisation will stop and regional development will become prominent. The second axis represents uncertainty about whether we are moving towards a world where economic development is leading with ongoing privatisation and trade liberalisation, or a world with increased solidarity, more interest for environmental issues and a stronger role for the government and the public sector.

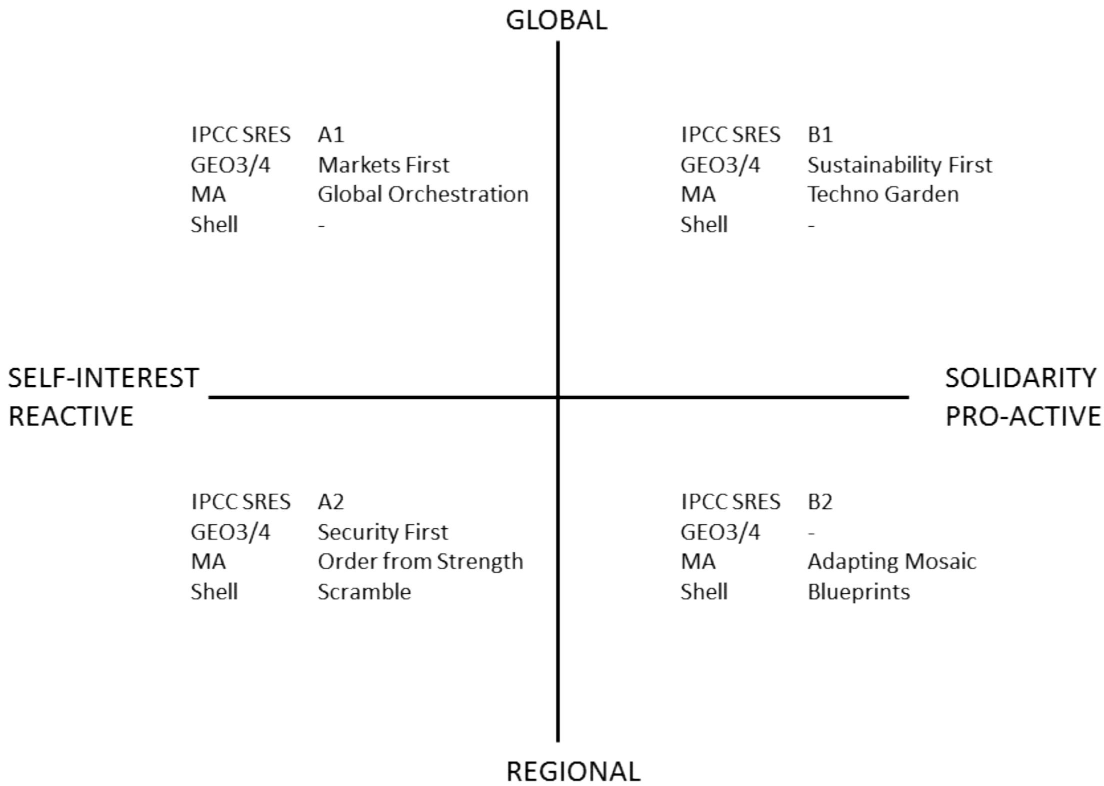


Figure 4.3: Selected global scenario sets positioned along two axes of main uncertainties. See Section 2.1 for explanations of the scenario studies.

The four resulting scenario archetypes (the four quadrants in Figure 4.3) can be described as follows:

I. **The Global Market** (top left quadrant). Global developments steered by economic growth result in a total dominance of international markets with a low degree of regulation. Environmental problems are only dealt with when solutions are of economic interest. SSP equivalent: SSP5.

II. **Continental Barriers** (lower left quadrant). A regionalised world based on economic developments. The market mechanism fails, leading to a growing gap between rich and poor. In turn, this results in increasing problems with crime, violence and terrorism, which eventuates in strong trade and other barriers. SSP equivalent: SSP3.

III. **Global Sustainability** (top right quadrant). A globalised world with an increasingly proactive attitude of policy-makers and the public at large towards environmental issues and a high level of regulation. Three main variations can be discerned. One where the global solution is in technological change (Techno Garden), one with strong governance structures (Policy First), and one with a broadly supported paradigm shift (Sustainability First). SSP equivalent: SSP1.

IV. **Regional Sustainability** (bottom right quadrant). A regionalised world, where most – broadly supported – initiatives to improve the state of the environment and move toward sustainable solutions are bottom-up with a major role for NGOs and multi-level governance structures. SSP equivalent: SSP1 (partly).

In conclusion, the bulk of the existing scenario studies can be categorised into a small number of scenario archetypes. This has important practical implications. Most importantly for IMPRESSIONS, it is possible to select one set of scenarios (i.e. SSP scenarios) and to use additional information from other studies, provided that scenario can be categorised in a similar archetype. Note that SSP4 does not have a direct equivalent; this world with high inequality but a "green" global elite can, however, be considered a mix between SSP3 and SSP1. Note also that the "Regional Sustainability" type of scenarios (lower right quadrant of Figure 4.2: B2, Adapting Mosaic) do not have a good fit with the SSPs.

4.5. European socio-economic scenarios

4.5.1. Starting point: The CLIMSAVE scenarios

A considerable number of partners within the IMPRESSIONS consortium were also part of a previous FP7 project, CLIMSAVE. From the onset, it was the intention to build on the material that was developed within CLIMSAVE. In the context of this deliverable, this importantly relates to a set of socio-economic scenarios that was developed for Europe and Scotland – the two case studies of CLIMSAVE. Besides the global SSPs, the CLIMSAVE socio-economic scenarios were identified as a second existing set of scenarios for Europe. The CLIMSAVE scenarios are described in detail in a series of project deliverables, importantly D1.2 (Gramberger et al. 2011a), D1.3 (Gramberger et al. 2012a), and D1.4 (Gramberger et al. 2013a). A short summary of the CLIMSAVE European socio-economic scenarios is provided below (see Figure 4.4):

Figure 4.4: Four European socio-economic scenarios positioned along two axes of main uncertainties.

We are the World: Effective governments change the focus from GDP to welfare, which leads to a redistribution of wealth, and thus to less inequality and more (global) cooperation.

Towards 2025: The financial crisis continues to have strong repercussions and EU leaders are forced towards further European financial policies. The crises fuel the feeling that behaviour has to change putting governments under pressure to take ambitious measures, including support for innovative research facilities. This results in a higher quality of life and a growing feeling of security and safety. Trade wars and crises are solved by the increased effectiveness of governments worldwide. By 2025, efforts to transform Europe and the rest of the world into a sustainable environment are now starting to pay their dividends.

Towards 2055: There is a focus on welfare rather than on GDP. The European Union has expanded further and the implementation of global governance advances. This also leads to a much safer world. On a technological level there is a lot more international competition as of 2030. A world constitution is adopted based on values such as equality and equal redistribution of resources for all. In 2050 technology has made it possible to live in a CO_2 neutral society. The redistribution of wealth globally has led to less inequality, more cooperation and a conflict free world.

Icarus: Short-term policy planning and a stagnating economy lead to the disintegration of social fabric and the shortage of goods and services.

Towards 2025: With the economy gradually picking up, the demand for resources increases, which turns out to be a tipping point for the state of the environment with severe ecosystem failures. Extreme weather events become more frequent and further increase the costs of resources, because of which the economy in Europe starts stagnating. In light of increasingly scarce public resources, long-term policy planning becomes rare with hardly any money for education, research or innovation. Eventually the EU breaks down.

Towards 2055: The stagnation of the economy leads to high unemployment rates and the breakdown of the social security system. This widens the gap between the haves and the have-nots. With the disintegration of social fabric, Europeans start to migrate to the BRIC countries, whose economies prosper. The impact of extreme weather events, together with economic decline bring about shortages of essential goods and services. Eventually some counter-movements are starting to take root with some signs of a slight economic recovery and post-modern values becoming more important.

Should I Stay Or Should I Go: Failure to address the economic crisis leads to an increased gap between rich and poor, political instability and conflicts; people live in an insecure and instable world.

Towards 2025: In an attempt to revamp the European economy quickly, policy-makers decide to invest in innovations with a big return on investment in the short run. Meanwhile, the depletion of natural resources continues and natural hazards increase in severity. Commodity prices go up and there is a slowly growing underclass that can no longer afford utility services. Attempts to find innovative solutions to combat the depletion of natural resources are unsuccessful. There is a widening gap in society, which feeds social unrest and triggers migration. Europe has altogether become a more dangerous place.

Towards 2055: Short economic revivals only add to the increasing gap between rich and poor, while most of society cannot adapt to the rollercoaster economy and suffers from health issues, unemployment, and poverty. The divide between the “affected” and “not affected” leads to conflicts over scarce resources, political instability and government failures. Governments start to regulate the use of resources very strictly and instate power cuts and water rationing. People start exchanging goods, work or services rather than paying for them. Organised crime has reached an all-time high and people live in an insecure and instable world.

Riders on the Storm: Strong economic recessions hit hard, but are successfully countered with renewables and green technologies. Europe is an important player in a turbulent world.

Towards 2025: Extreme weather events lead to food shortages and price increases, and suppress economic growth. Yet, the EU is committed to finding innovative solutions to the depletion of natural resources and climate change. Key to this strategy is public-private collaboration. The constructive approach makes the EU stronger and more influential, while global political stability decreases. The lack of a global market for green technology triggers a strong economic recession.

Towards 2055: Counter measures in the EU are successful with high energy efficiency and renewable sources reducing the dependency on natural resources. Additionally, people have become used to a lower standard of living. A new wave of severe climate change impacts does not affect Europe but hits hard in the rest of the world. Europe displays a steady green GDP growth and an increase in purchasing power, which is reflected in a population increase. The demand for green technology has also grown with the recovery of the world economy. The enormous investments finally pay off. Although the world economy remains turbulent, Europe is an important player.

4.5.2. Matching the SSPs and the CLIMSAVE scenarios

A number of methodological decisions needed to be taken in order to conceptualise the use of two existing sets of scenarios. Table 4.1 shows the CLIMSAVE scenarios with illustrative examples of three uncertainties as identified by stakeholders, together with the most similar SSP.

Table 4.1: CLIMSAVE scenarios for Europe with illustrative examples for economic, environmental and social uncertainties, and most similar SSP.

Scenario	Economic	Environmental	Social	SSP
We are the World	Gradual increase	Effective solutions	High social cohesion	SSP1
Icarus	Gradual decline	Ineffective solutions	Decline, then picking up	SSP3
Riders on the Storm	Rollercoaster downwards	Effective solutions	Low social cohesion	SSP4
Should I Stay or Should I go?	Rollercoaster up and down	Ineffective solutions	Low, but growing	No SSP equivalent

Analysis of Table 4.1 and other elements within the CLIMSAVE and SSP scenarios revealed:

- Three out of four SSPs match to greater or lesser degree one of the CLIMSAVE scenarios.
- The strongest match is with the Utopian SSP1 (We are the World) and the Dystopian SSP3 (Icarus). A fair match is found with SSP4 (Riders on the Storm), mostly in relation to strong economic growth, which spurs consumption and leads to a rapid use of natural resources including fossil fuels. The match with SSP5 is poor, mostly because of the fundamental assumption of strong fossil-fuel dominated energy consumption, in combination with lack of interest in natural capital. This is not assumed in Should I Stay or Should I Go.
- Overall, the SSPs assume a higher economic growth than the CLIMSAVE scenarios. Social sustainability is likewise lower in the European CLIMSAVE scenarios.

In conclusion, the SSPs and the CLIMSAVE match to a degree sufficient to assume that they could be synchronised further and linked. This is particularly the case for SSP1 and SSP3, and to some extent for SSP4. Linking SSP5 and CLIMSAVE is more challenging.

When combining the SSP and CLIMSAVE scenarios, it is necessary to decide which should be leading. It was decided that, in principle, the global SSPs should be leading, for several reasons:

- The CLIMSAVE scenarios have a time horizon of 2055 whilst the IMPRESSIONS European socio-economic scenarios should have an outlook until 2100.
- The CLIMSAVE scenarios use other main uncertainties to lay out the basic foundation of the scenarios. Using these as a starting point would deviate from scenario development in other case studies and, hence, loose cross-scale consistency.
- The CLIMSAVE scenarios lack a version of SSP5, which in terms of linking with RCP8.5 (see Section 2.3.2) is very important and would need to be added.

However, there are also a number of drawbacks associated with this decision:

- The CLIMSAVE scenarios are much richer and specific for Europe. Some of the detail and richness of the stories cannot be used.
- The SSPs are global scenarios, focusing on aspects that globally lead to highly contrasting scenarios. For Europe, this is not necessarily the case, particularly considering the pairs SSP1/SSP5 and SSP3/SSP4. The CLIMSAVE scenarios are contrasting.

Furthermore, the CLIMSAVE scenarios were developed during a series of three stakeholder workshops and it is important to ensure stakeholder acceptance of using the global SSPs as a starting point. IMPRESSIONS, likewise, uses stakeholder workshops as the main method for developing socio-economic scenarios. A number of steps were taken to help overcome this issue:

- An expert meeting was organised (January 2015 in Wageningen, the Netherlands) during which a foundation was laid for a set of European SSPs, based on the CLIMSAVE scenarios and the global SSPs. The goal of the meeting was to draft a set of scenarios that would serve as a set of extended European SSPs, while maintaining the flavour of the CLIMSAVE scenarios.
- An online discussion with a small selection of stakeholders will be initiated to discuss the set of draft European SSPs.
- The European SSPs will be discussed during the next upcoming European stakeholder workshop.

Note that the risk of stakeholders rejecting a scenario is very small for SSP1 and SSP3 as they have a strong link with the CLIMSAVE scenarios. The risk is larger for SSP5 as this does not have a CLIMSAVE equivalent and will require a new socio-economic scenario for Europe to be developed.

4.5.3. The European SSPs

The European scenario development took place as part of the IMPRESSIONS activities. As such, the results from the meeting in January 2015 in Wageningen are not “existing scenarios”. Yet, the European SSPs are the starting point for the first stakeholder workshops in Iberia and Hungary and are, therefore, documented in this deliverable. The full versions of the European SSPs are work in progress; what is reported here are the set of key elements and a summary of the narrative. These are longer and more detailed for those SSPs where there is a good match with the CLIMSAVE scenarios (SSP1 and SSP3). As this is work in progress, it is subject to change as IMPRESSIONS progresses, and particularly based on feedback from the second stakeholder workshop when the European SSPs will be discussed with stakeholders.

Key elements

An overview of key elements for the four European SSPs is given in Table 4.2. The list of elements is based on the set of key uncertainties that is part of the CLIMSAVE scenarios and the tables with key elements as presented in O'Neill et al. (2015) describing the global SSPs. The final list was drafted during the expert workshop in Wageningen, in January 2015. Note that there is a good match for most key elements.

Table 4.2: Key elements of the European SSPs with an indication of the corresponding key element in the global SSPs and trends until 2100 for each scenario.

European SSP element	**Global SSP element**	**SSP1-WATW**	**SSP3-Icarus**	**SSP4-ROTS**	**SSP5-SISOSIG (start from SSP storyline)**
Decision-making level	*Institutions*	International/EU leader more than MS	National\Local+ fragmentation	International / European	International/EU not a leader on the global scale
Geopolitical stability	*Combination of institutions and international cooperation*	High	Low	High	High
International cooperation	*International cooperation*	Strong, EU important player	Weak	Strong	Strong (trade)
Social respect	*Societal participation*	High	Low between countries	Low, respect between societies	High
Net migration- low in-migration	*Population growth/ migration*	Low in-migration	Out-migration	Selected in-migration	High to cities and from poorer countries
Economic develop-ment	*Economic growth*	Gradual (with hiccups at the beginning)	Low	High	High
Mobility	*Migration*	No barriers, but movements are limited	Low	High	high
Globalisation	*Globalisation*	Unconstrained	Constrained	Uncontrolled (only controlled in parts)	Unconstrained
Choice	*Policies*	Free, but strong regulation on land use	Restricted	Free for elites	Free
Social cohesion	*Social cohesion*	High	Low EU\higher within countries	Low	High
Technology development	*Technology development*	High, but not pervasive	Low	High in some areas; low in labour intensive areas	Strong and crucial
Quality of Governance	*Policy orientation*	High – focus on sustainability	Low and ineffective	High and effective	High – focus on businesses
Human health investments	*Health investments*	High	Low	High for elites	High
Education investments	*Education*	High	Low	High for elites	High
Environmental respect	*Environmental policy*	High	Low	High in pockets	Low, but high NIMBY

European SSP1 / We Are the World (WATW)

Within WATW, there is a high commitment to achieve development goals through effective governments and global cooperation, ultimately resulting in less inequality and less resource intensive lifestyles.

2010-2040: The financial crisis continues to have strong repercussions and EU leaders are forced towards further European financial policies. The crises fuel the feeling that behaviour has to change putting governments under pressure to take ambitious measures, including stimulating an energy transition towards renewables and a general support for innovative research facilities. This results in a higher quality of life and a growing feeling of security and safety. Trade wars and crises are solved by the increased effectiveness of governments worldwide. By 2040, efforts to transform Europe and the rest of the world into a sustainable environment are now starting to pay their dividends, reinforced by changing lifestyles.

2040-2070: A decrease in conflicts in developing regions leads to higher political stability and slower economic development. The European Union expands further and participates in new global governance initiatives. They thus take account of their responsibility for environmental impacts in developing regions and lead investments into sustainable development. As a result, migration towards Europe starts to decline for the first time this century. There is a substantial shift in the European political agenda with a greater focus on well-being than economic growth, driven by human losses associated with climate change combined with positive improvements in accessible education and lifestyle. Advances in technology that are stimulated by international competition lead to a CO_2 neutral society by 2050.

2070-2100: The redistribution of wealth globally leads to less inequality, more cooperation and a conflict free world. Europe is characterised by an environmentally-friendly political and social awareness, focusing on renewable energy, low material growth and strong international cooperation.

European SSP3 / Icarus

Sparked by economic woes in major economies and regional conflict, antagonism between and within regional blocs increases, resulting in the disintegration of social fabric and many countries struggling to maintain living standards. Ultimately, a high-carbon intensive Europe emerges with high inequalities.

2010-2040: With the economy gradually picking up, the demand for resources increases, which turns out to be a tipping point for the state of the environment with severe ecosystem failures. At the same time, the economy does not perform as expected with new crises across the continent that stress the structural differences across and within countries. Populist movements become increasingly mainstream and are further fuelled by increasing riots in multicultural neighbourhoods. The persistence of conflicts and decline in trade also affects energy and food prices. Extreme weather events become more frequent and further increase the costs of resources; this causes the economy in Europe to start to stagnate. This, in turn, increases unemployment rates and leads to the phasing out of the social security system. In light of increasingly scarce public resources, long-term policy planning becomes rare with hardly any money for education, research or innovation. Eventually the EU breaks down.

2040-2070: Continuing negative social, environmental, and economic developments widen the gap between the haves and the have-nots. With the disintegration of social fabric, Europeans start to migrate in search of jobs, and are employed in countries that are somewhat better off, for relatively low wages. Eventually some counter-movements appear with some signs of a slight economic recovery. Yet, these signs are temporary and do not take root in an increasingly fragmented world with strong regional rivalry and conflict. The general lack of technology transfer and economic resources, coupled with weak institutions and governance structure, leads to an increasing resource intensity and fossil fuel use, including burning wood.

2070-2100: In the absence of strong (inter)national institutions, criminal organisations and corruption take hold across Europe, in the aftermath of failed counter movements. New clean technologies are illegally transferred from the BRIC countries to Europe, but only for those that can afford it. This ensures clean water, clean energy and health for the 'haves'. However, the majority of the people (the have-nots) accept political instability, social injustice and extreme climatic conditions as the status quo and learn to live with less.

European SSP4 / Riders on the Storm (ROTS)

Globally, power becomes more concentrated in a relatively small political and business elite, accompanied by increasing disparities in economic opportunity, leading to substantial proportions of populations having a low level of development. Because of successful green technologies, Europe becomes an important player in a turbulent world, despite growing inequalities.

Key questions to be addressed to fully match global SSP4 and CLIMSAVE Riders on the Storm:

- Will Europe be "an important player", being relatively better off than the rest of the world? Current levels of (high) social cohesion and energy efficiency, coupled with environmental policy-making could lead in that direction.
- To what extent will society become unequal? Are inequalities within countries, within Europe, and/or between (trade) blocs? SSP4 focuses on social stratification within countries, but also hints at other inequalities. ROTS hints at a strong EU and low social cohesion.
- To what extent will social stratification affect the functioning of the EU? What is the role of the middle class?

European SSP5 / Should I Stay or Should I Go (SISOSIG) or no CLIMSAVE equivalent

Globally, driven by the economic success of industrialised and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. A lack of environmental concern leads to the exploitation of abundant fossil fuel resources. In Europe, likewise innovations lead to a big return on investments and increased social equity and health. This puts pressure on the environment, but negative impacts are addressed effectively by technological solutions.

Key questions to be addressed:

- Does there need to be any attempt to link SSP5 with CLIMSAVE Should I Stay or Should I Go? The scenarios have a poor match. Note that in SISOSIG, Europe is worse off than the rest of the world. This seems implausible within the context of SSP5.
- What are specific European developments? Are fossil fuels sufficient? Will there be a lack of environmental concern within Europe? How would this come about?

4.6. Scottish scenarios

4.6.1. Starting point: The CLIMSAVE scenarios

Similar to the European case study, the CLIMSAVE project developed socio-economic scenarios for Scotland on which we could build in IMPRESSIONS (Gramberger et al. 2011b; 2012b; 2013b). A short summary of the CLIMSAVE Scottish socio-economic scenarios is provided below (see Figure 4.5).

Figure 4.5: Four Scottish socio-economic scenarios positioned along two axes of main uncertainties.

Tartan Spring: 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 a "Tartan Spring" revolution.

Towards 2025: Scotland continues to be a prosperous country benefitting from a strong government-led management of its abundant (natural) resources. Technological innovation, driven by an increasingly strong private sector, leads to more efficient use. The downside is a huge immigration of elderly people, depressing economic growth. Additionally, multinationals have taken control of Scotland's resources. Following the first immigration wave of high-skilled professionals, comes a wave of lower-skilled labourers. Scotland starts its path towards independence which is completed in 2030.

Towards 2055: A far-reaching but poorly regulated privatisation is initiated, with Scotland leaving the EU to become a major player on the global market. This has a range of negative consequences: The end of the welfare state, erosion of social fabric and decreasing influence of the local community level. Most people cannot sustain their standard of living. A class of poor citizens emerges, while the wealthy move into eco-communities. Eventually, continuous strikes and protests by the dispossessed paralyse the country. In 2051, insecurity ends up in a "Tartan spring" revolution. The Scottish government is overthrown by the dispossessed. Scotland enters turbulent times.

Mad Max: Driven by crises, a new self-centred paradigm emerges, which leads to a growing disparity in society. A survival from day-to-day prevails, while 'clans' are ruling Scotland again.

Towards 2025: A mix of financial crisis and extreme weather events hits the agricultural sector hard. Increasingly more people have problems buying food and water and eventually a new self-centred paradigm emerges. Because of weak governments, multinationals increase their grip on society. The self-centred, profit driven system leads to a disparity between the "haves" and the "have-nots". Fragmentation of society leads to more sectarianism. Black markets for food, water, clothes and jobs are sprouting all over Scotland and cheap labour is the only sort of employment. The whole European Union suffers from social unrest and an economic and energy crisis.

Towards 2055: A survival from day-to-day prevails over a long-term structural approach for the have-nots as well as for the Scottish government. Ghettos of poor people living on boats emerge. At the same time, the rich increase their grip on society. 'Clans' are ruling Scotland again. Over time, the "haves" and "have-nots" organise themselves, but fundamental problems remain. By 2050, the Scottish economy and society have somewhat stabilised.

The Scottish Play: Building on traditional Scottish values, a lack of resources is dealt with by change in lifestyle towards reducing, re-using, and recycling, leading to a poorer but greener and happier population.

Towards 2025: Scotland feels the effects of the financial crisis and climate change. The government bails out the agricultural sector by investing more in climate change mitigation. The oil price peaks and revenues are used for education and health care. Scotland is doing relatively well. Agriculture becomes the growing core of the economy. Meanwhile, the traditional Scottish values of getting on with it, no desire for excess, and sense of solidarity take the upper hand. Some people move to the countryside seeking a better quality of life and cheaper living cost. Life in Scotland remains attractive, mainly because the rest of the world is suffering more.

Towards 2055: All strata of society bear the fruit of the investments in the education system, stimulating widespread innovation and creativity. Scots have learned to cope with difficult and quickly changing living conditions, through a modest approach. The three 'R's' – Reduce, Re-use, Recycle – have become the motto of Scottish economy. The renewable energy sector grows, but energy remains expensive and its distribution limited. The Scottish population may be poorer than a few decades ago, but they are also greener and happier. Scotland, however, does not become independent.

Mactopia: Initially stimulated by a resource surplus, Scotland makes 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.

Towards 2025: Scotland takes a conscious decision to make a transition towards an equitable and sustainable society, which requires strong government regulation. Actions are stimulated by an increasing independence from the UK. Business costs tend to increase, but these are outweighed by the benefits of a resource surplus. The industry is focused on innovation and technology. Not just the resources are being sold, but also the intellectual property surrounding it. The strong economy and equitable lifestyle of Scotland attracts many immigrants from throughout the European Union and beyond.

Towards 2055: Scotland begins to play an important role in services worldwide, diversifying away from natural resources, becoming a frontrunner in IT, life sciences, green technology and finance. On the other hand, tax evasion increases in heavily taxed Scotland, as do illegal activities. Scotland attracts even larger numbers of immigrants, that do not always receive a warm welcome, but help to reinvigorate local communities. Eventually, the rich may have become slightly less rich, but poverty is almost eradicated and a powerful middle class now takes the lead in Scotland.

4.6.2. Matching the SSPs and the Scottish CLIMSAVE scenarios

Similar to Europe, a number of methodological decisions needed to be taken in order to conceptualise the use of two existing sets of scenarios. Table 4.3 shows the CLIMSAVE scenarios with illustrative examples of three uncertainties as identified by stakeholders, together with the most similar SSP.

Table 4.3: CLIMSAVE scenarios for Scotland with illustrative examples for economic, environmental and social uncertainties, and most similar SSP.

Scenario	Economic	Environmental	Social	SSP
Tartan Spring	Strong but weakening	Weak environmental regulation	Disparate well-being	SSP4
Mad Max	Rollercoaster volatile	Non-existent	Disparate	SSP3
The Scottish Play	Gradual strong with blips	Trade-offs	Equitable	(SSP5)
MacTopia	Strong	Integrated	Equitable	SSP1

Analysis of Table 4.3 and other elements within the Scottish CLIMSAVE and SSP scenarios revealed:

- All SSPs match one of the Scottish CLIMSAVE scenarios to greater or lesser degree.
- The strongest match is with the Utopian SSP1 (MacTopia) and the Dystopian SSP3 (Mad Max). A fair match is found with SSP4 (Tartan Spring), although the uprising (the "Tartan Spring") would need to be assumed not to have any lasting effects. The match with SSP5 is poor.
- Overall, the SSP/CLIMSAVE pairs are very similar to the European scenarios.

In conclusion, the SSPs and the Scottish CLIMSAVE scenarios match to a degree sufficient to assume that they could be synchronised further and linked. This is particularly the case for SSP1 and SSP3, and to some extent for SSP4. Similar to Europe, linking SSP5 and CLIMSAVE is most challenging.

In contrast to the European SSPs, it was decided that the Scottish CLIMSAVE scenarios should be leading rather than the global SSPs, where possible. This translates to using the full narratives of the Scottish CLIMSAVE scenarios where there is a good match with the SSPs (SSP1, SSP3). For SSP4, the Scottish CLIMSAVE scenario is used as a starting point, but with alterations where needed in case of inconsistencies with the global SSP4. For SSP5, a new narrative will need to be written, making use of elements of The Scottish Play scenario, where appropriate. The decision to have the Scottish scenarios leading has several pros and cons.

Advantages are:

- Facilitates buy-in from stakeholders. The composition of the group of stakeholders that will be developing scenarios in IMPRESSIONS will be largely the same as in CLIMSAVE. It is, therefore, mandatory rather than advantageous to use the CLIMSAVE scenarios that they themselves developed as a starting point, rather than a set of global scenarios.
- Provides specificity and detail for Scotland. The global SSPs contain very little information that can be used to shape Scottish scenarios, because of the large scale-mismatch. Starting with Scottish scenarios provides a richer, more credible, and more useful starting point.

Drawbacks of the decision include:

- The CLIMSAVE scenarios cover the period until 2055 and need to be extended to 2100. A match between SSPs and CLIMSAVE needs to be established in order to be able to use the SSPs to extend the CLIMSAVE scenarios.
- The CLIMSAVE scenarios use other main uncertainties the lay out the basic foundation of the scenarios. Using them as a starting point might hinder matching with the SSPs.
- The CLIMSAVE scenarios lack a version of SSP5, which needs to be written based on the global story. This disadvantage has been realised and an extra workshop is planned for September 2015 to develop a Scottish version of SSP5 with the stakeholders. Drafts of all four IMPRESSIONS socio-economic scenarios for Scotland, based on CLIMSAVE and the global/European SSPs, will also be discussed at this workshop. Note that the risk of stakeholders rejecting a scenario is very small for SSP1 and SSP3, as they will be highly related to the Scottish scenarios. SSP4/Tartan Spring will need some merging of the main CLIMSAVE elements until 2055 and some longer term developments taken from SSP4.

4.6.3. The Scottish socio-economic scenarios

At the time of writing, a draft of the Scottish socio-economic scenarios was not available. Moreover, and contrary to Europe, we wish to refrain from documenting a draft that has not been discussed with the stakeholders. It is likely that three scenarios will be very similar to the CLIMSAVE products (MacTopia, Mad Max, and Tartan Spring) and one will be developed based on SSP5.

4.7. Scenarios in other case studies

In general, much less information on existing scenarios was considered for the other three case studies, for several reasons:

- Not available. In two cases (Hungary and EU-external), there is an almost total absence of socio-economic scenarios for the region.
- Not the right focus. Scenarios on specific sectors were available particularly for (parts of) Iberia, but too distinct from the SSPs or socio-economic scenarios to be deemed useful.
- Not the right scale. Scenarios for specific watersheds or regions (e.g. for Spain or for Portugal) were available.
- Not useful for socio-economic scenarios. Last but not least, scenarios in all shapes and forms exist, mostly quantitative and linked to (sectoral) impact models. For instance, the Guadiana watershed AND the Tagus watershed in Iberia have been exhaustively studied, also using scenarios. Yet, most information is available as model output rather than socio-economic scenarios.

Rather than providing an overview of existing material that was not used, we limit ourselves here to a few case study specific remarks.

4.7.1. EU-external (central Asia)

Within the EU-external case study, scenarios will be developed for a region of five countries in Central Asia (Kazakhstan, Kyrgyzstan, Turkmenistan, Uzbekistan and Tajikistan). This region was selected such that it covers a region that might have strong indirect impacts on developments in Europe and European policy-making. Conceptually, there is a strong link between the European case study and the EU-external case study. Consequently, there also needs to be a strong resemblance between the sets of European and EU-external scenarios. We therefore opted for a similar process in the development of participatory socio-economic scenarios, with the aim of developing EU-external versions of SSP1, SSP3, SSP4 and SSP5. With this specific aim, it was decided to refrain from using existing material but to develop socio-economic scenarios based on the global and European SSPs. This was undertaken in a stakeholder workshop in the region in February 2015, and the narratives, tables of elements and quantified values resulting from this workshop are currently being analysed. Existing model results for the region might be considered as (global) IAMs start modelling the full set of SSPs and RCPs.

4.7.2. Iberia

This case study consists of two countries (Spain and Portugal) and two transboundary watersheds (Guadiana and Tagus). For any of these, scenario studied have been executed. Yet, for the region as a whole, the number of scenario studies is very limited. The specific aim of the participatory scenario exercise is to construct multi-scale scenarios, consisting partly of future outlooks for Iberia and partly for the two watersheds, focusing on transboundary issues. As said, both watersheds have been the subject of investigation of many research projects, particularly related to drought, land degradation, and the agricultural sector. Although socio-economic scenarios have been developed as part of these endeavours, none were found that were current, scientifically accepted, rich in detail on socio-economic stories as well as quantitative model output, and – importantly – extending to 2100. Given the possible difficulties with merging existing scenarios with developing new ones (see previous sessions on matching SSPs and CLIMSAVE scenarios), we decided to develop socio-economic scenarios from scratch, based on the European SSPs as documented in Section 4.5. Because of the specific focus on transboundary issues, it is expected that four versions of the SSPs will be developed, but with a partly different content to be useful for the specific context. This has been termed “controlled divergence”.

4.7.3. Hungary

This is the most local case study within IMPRESSIONS, focusing on two municipalities and including local impacts and local adaptation options and strategies. At the national level, scenario studies are available, particularly related to the accession of Hungary to the EU and its potential future effects. Although not unimportant, existing scenarios can be characterised as rather short-term, mostly somewhat outdated, and/or having no specific information on climate change (impacts). For similar reasons as for Iberia, it was decided to develop socio-economic scenarios from scratch. These scenarios will be based on the European SSPs to the extent possible.

5. Integration between climate and socio-economic scenarios

As stated in Chapter 2, by embarking upon a parallel and compartmentalised process of scenario development, the integration between climate and socio-economic scenarios has become a crucial aspect of the methodology, both at the global level and for IMPRESSIONS. The final integrated scenarios will not be completed until close to the finalisation of the project, in Deliverable 2.4. Yet, a number of methodological decisions need to be taken to ensure that integration is possible. Some of these considerations and decisions are outlined in this Chapter, mostly to document our current thinking of how two essentially independently developed products – climate and socio-economic scenarios – will ultimately be part of one set of integrated scenarios.

5.1. Background and rationale to the selected RCP x SSP combinations

This section provides more detail and background on the rationale behind the selection of RCPs, SSPs, and RCP x SSP combinations.

A first step in the process of integration is the selection of a (small) number of RCP x SSP combinations that will be considered throughout IMPRESSIONS. The overall idea was to select a number of combinations of RCPs and SSPs that fulfil the following requirements:

- The RCPs are high-end;
- The SSPs cover a broad range of socio-economic developments;
- The SSPs relate to the CLIMSAVE scenarios;
- Any combination of SSPs and RCPs is plausible (or at least not impossible), meaningful and useful; and
- The set of combinations covers a range of (high-end) future outlooks.

Using this logic, we strongly reduced the number of possible combinations by:

- Excluding SSP2 as this is not high-end in any way, and is not covered by the CLIMSAVE scenarios;
- Excluding RCP2.6 as not being sufficiently high-end; and
- Excluding specific implausible combinations (e.g. SSP1 and RCP6.0/8.5; SSP5 and RCP4.5).

Based on this initial reduction, it was decided to select two RCPs (RCP4.5 and RCP 8.5) that cover the range of temperature change from 2-6 degrees. It was furthermore decided to include four SSPs by excluding SSP2. To further reduce the number of combinations two tables were produced and discussed (Tables 5.1 and 5.2) in which the plausibility of the eight remaining combinations is indicated, both at the global and case study level.

Table 5.1: Global RCP x SSP combinations with an indication of the plausibility of the combination.

RCP (W/m^2)	**T change**	**SSP**			
		SSP1	**SSP3**	**SSP4**	**SSP5**
4.5	2-4	Possible	Possible	Possible	Possible
8.5	3-6	Very unlikely	Possible	Unlikely	Most likely

Table 5.2: Regional RCP x SSP combinations with an indication of the usefulness of the combination.

RCP (W/m^2)	**T change**	**SSP**			
		SSP1	**SSP3**	**SSP4**	**SSP5**
4.5	2-4	Not very challenging	Challenging	Useful	Less credible
8.5	3-6	Very interesting	Interesting	Less credible	Interesting

Note that plausibility of RCP x SSP combinations only applies to the global/European level. At more local scales (i.e. Scotland, Iberia, Hungary), it can be totally plausible to have socio-economic futures that lead to low emissions, while the RCP assumes high emissions (e.g. from China). This would be something to discuss with stakeholders during the final cross-scale workshop.

The consequences of aiming at one set of combinations that are plausible at the global level and useful at the regional level were discussed, with the following conclusions:

- A good candidate to include is the dystopian SSP3 with RCP8.5 and/or RCP4.5. This would represent a gloomy future with strong climate change (impacts).
- A second good candidate is the fossil-fuelled development in SSP5 with RCP8.5. This would cover extreme climate change with a society that is equipped to deal with it.
- A third good combination is the inequality of SSP4 with RCP4.5. SSP4 is a very interesting addition to the global scenarios that is worthwhile to explore and compatible with at least RCP4.5.
- A last combination to consider is the utopian SSP1 with the most extreme RCP that is deemed plausible in combination with such a sustainable society, i.e. RCP4.5.

Therefore, the following four combinations were proposed as a minimum set to be used in all case studies in IMPRESSIONS:

1. SSP1 x RCP4.5
2. SSP4 x RCP4.5
3. SSP3 x RCP8.5
4. SSP5 x RCP8.5

This links the SSPs with low mitigation challenges (SSP1/4) to RCP4.5 and high mitigation challenges (SSP3/5) to RCP8.5. Furthermore, both low adaptation challenges (SSP1/5) and high adaptation challenges (SSP3/4) are confronted with RCP4.5 and RCP8.5. After subsequent discussions a fifth combination was proposed:

5. SSP3 x RCP4.5

The rationale is that with this addition, the effect of changing the RCP, under the same SSP is possible. In addition, both RCP8.5 and RCP4.5 seem to match SSP3.

By having a certain amount of flexibility to vary the amount and type of climate change within an RCP through the choice of GCM/RCM as discussed in Chapter 3, we keep options open to further discuss the exact nature of the combinations.

5.2. From scenarios to climate change impacts and vulnerability

The choice of RCP x SSP scenario combination is just the first step in a series of decisions that need to be taken before climate and socio-economic scenarios can be integrated with climate change impacts and vulnerability. Adaptation/mitigation options and other actions can only be meaningfully discussed when socio-economic developments and climate change impacts are brought together. Below is a short overview of those steps which are elaborated in the scenario protocol for impact modellers within Deliverable D3.1. The final details of the implementation need further discussion between the different WPs of IMPRESSIONS:

- Step 1. Selection of RCPs and SSPs.
- Step 2. Selection of climate models (see Chapter 3). For climate scenarios, climate model uncertainty can be as, if not more, important than emissions scenario uncertainty. The choice of a subset of climate models is, therefore, crucial.
- Step 3. Run impact models to assess climate change impacts and select relevant indicators for sectoral and cross-sectoral impacts as well as coping and adaptive capacity.

- Step 4. Assess the vulnerability of society within the different SSPs to the climate change impacts.
- Step 5. Discuss results with stakeholders and develop adaptation and mitigation options/pathways to reduce or cope with the vulnerability.
- Step 6. Test the adaptation and mitigation pathways with the impact models under the different RCP x SSP scenario combinations.
- Step 7. Discuss results with stakeholders to refine the adaptation and mitigation pathways, and develop innovative transformative strategies that take account of cross-sectoral, cross-scale and adaptation-mitigation synergies.

5.3. Integration of climate and socio-economic scenarios

IMPRESSIONS aims to develop integrated scenarios. These can be obtained in two different ways:

1. Integration between climate and socio-economic contextual exploratory scenarios. These are needed before the start of the second set of participatory workshops and provide the context within which adaptation/mitigation options, strategies, and pathways will be developed by stakeholders. This is referred to below as “integration through stories”:
    a. Develop climate and socio-economic scenarios;
    b. Provide information on RCPs, climate change, and climate change impacts to stakeholders;
    c. INTEGRATION: Alter socio-economic scenario to reflect impact of climate change;
    d. Stakeholder-produced integrated socio-economic scenario is used as contextual information when discussing adaptation/mitigation options.

2. Integration between a range of (forward-looking) products, including climate and socio-economic scenarios, but also pathways and (selected) modelling results. This is referred to as “integration through models”:
    a. Develop climate and socio-economic scenarios;
    b. Derive and quantify socio-economic model inputs;
    c. INTEGRATION: Run impact models with the climate and socio-economic scenario combinations to compute integrated impacts and vulnerability.
    d. Use modelled integrated impacts and vulnerability to guide discussions with stakeholders on adaptation/mitigation options.

“Traditional” integration is achieved through models, in which “clean” SSPs are used as an input. The integration through stories was added because of the focus on high-end scenarios and the long time horizon. These two together can lead to extreme climate change impacts, which could potentially change the underlying socio-economic assumptions, which creates a dependency between socio-economic and climate scenarios prior to the phase of discussing policies and pathways. Figure 5.1 provides a schematic overview of the two routes of integration.

Discussions on how to best allow for both possibilities of integrating climate and socio-economic scenarios are in their early phase. Yet, a number of methodological considerations stand out: If stakeholders discuss the impact of climate change on the socio-economic scenario, SSP variables get changed during the process of developing SSP(int) that will later again be changed when implementing adaptation and mitigation options. This double counting can be avoided by aiming at two socio-economic scenario products, a “clean” SSP and an “integrated” SSP. The SSP(int) cannot be used to feed the models, as it is tied to one specific RCP with one specific climate sensitivity and one specific climate model and it cannot be used to explore other combinations. For this, the clean

SSP is appropriate. Fuzzy Sets will be applied to quantify the SSPs. Iteration between model results and SSPs needs to be with the clean SSPs and not with the SSP(int) that have not been quantified.

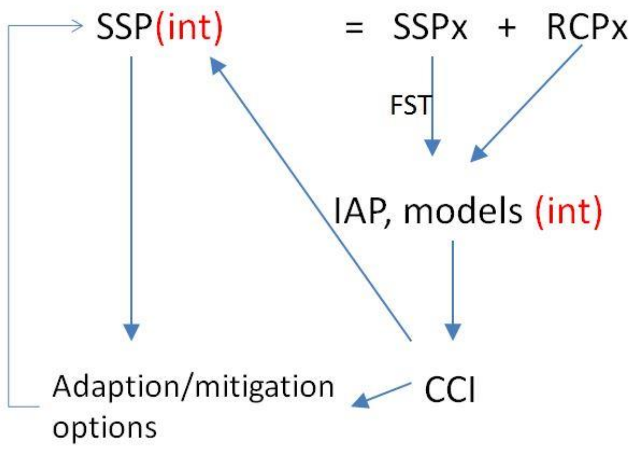


Figure 5.1: Schematic overview of two routes of integration. The first route qualitatively integrates the SSPs and RCPs, leading to SSP(int) that set the context for adaptation/mitigation options. The second route quantifies SSPs using Fuzzy Set Theory (FST). Quantitative model input feeds impacts such as the CLIMSAVE Integrated Assessment Platform (IAP), which enables the calculation of climate change impacts (CCI).

A number of possible solutions are being proposed to deal with having two types of integrated and two types of socio-economic scenarios:

1. Accept as is. Both are integrated, just in other ways and at other moments. Both help provide an integrated context.
2. Refrain from explicitly developing SSP(int), but maintain a separation between the SSPs and RCPs, similar to the modelling logic. The two would be combined through the impact modelling, but without explicitly changing the stories, and thus without an SSP(int).

At the time of writing, a preliminary method for integration was proposed and implemented for the first stakeholder workshop in the EX-external case study. The method consisted of a presentation on the main changes in climate based on the RCPs and the main climate change impacts based on the IPCC AR5 and other literature. This was then followed by a (short) session during the workshop during which implications of climate change and climate change impacts for socio-economic development were discussed. This starts the process for consideration of SSP(int) as discussed in solution (1) above. At the second set of stakeholder workshops, results from the impact models within IMPRESSIONS will be available following the integration logic of solution (2) above. Further discussion is needed to bring together these different approaches to integration before the second set of stakeholder workshops in 2016.

6. Acknowledgements

The authors would like to thank all members of the IMPRESSIONS Scenario Team for their valuable input in the discussions that led to the text of this deliverable. With the risk of forgetting someone, we would particularly like to thank Paula Harrison, Mark Rounsevell, Ian Holman, Laszlo Pinter, David Tabara, Henrik Carlsen, Diana Mangalagiu and Niki Franzeskaki. Also all participants in the workshop in Wageningen are acknowledged for their role in developing the European SSPs.

7. References

Busch, G. (2006). Future European agricultural landscapes – What can we learn from existing quantitative land use scenario studies? Agriculture, Ecosystems and Environment, 114: 121-140.

Christensen J.H., E. Kjellström, F. Giorgi, G. Lenderink and M. Rummukainen (2010). Weight assignment in regional climate models. Clim. Res., 44, 179-194, doi: 10.3354/cr00916.

Christensen, J.H. and O.B. Christensen (2007). A summary of the PRUDENCE model projections of changes in European climate by the end of this century, Climatic Change, 81 Supl. 1, 7-30, doi: 10.1007/s10584-006-9210-7.

Christensen, J.H., K. Krishna Kumar, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie and T. Zhou (2013). Climate Phenomena and their Relevance for Future Regional Climate Change Supplementary Material. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Christensen, O.B., S. Yang, F. Boberg, C. Fox Maule, M. Olesen, M. Drews, H. J. D. Sørup and J.H. Christensen (2015). Scalability of Regional Climate Change in Europe for High-End Scenarios, Clim. Res., [In press]

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner (2013). Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Déqué, M. and S. Somot (2010). Weighted frequency distributions express modelling uncertainties in the ENSEMBLES regional climate experiments, Clim. Res., 44, 195-209, doi: 10.3354/cr00866.

Dubrovsky, M., M. Trnka, I.P. Holman, E. Svobodova, P.A. Harrison (2015). Developing a reduced-form ensemble of climate change scenarios for Europe and its application to selected impact indicators. Climatic Change, 128, 169-186.

Ebi, K.L., Hallegate, S., Kram, T., Arnell, N.W., Carter, T.R., Edmonds, J.A., Kriegler, E., Mathur, R., O'Neill, B.C., Riahi, K., Winkler, H., Van Vuuren, D.P. & Zwickel, T. (2014). A new scenario framework for climate change research: background, process, and future directions. Climatic Change, 122: 363-372.

Gramberger, M., Kok, K., Eraly, E. & Stuch, B. (2011a). Report of the first regional stakeholder workshop of CLIMSAVE. CLIMSAVE Deliverable 1.2a.
http://www.climsave.eu/climsave/doc/Report_on_the_first_regional_workshop.pdf

Gramberger, M., Kok, K., Eraly, E. & Stuch, B. (2011b). Report of the first European stakeholder workshop of CLIMSAVE. CLIMSAVE Deliverable 1.2b. http://www.climsave.eu/climsave/doc/Report_on_the_first_European_workshop.pdf

Gramberger, M., Kok, K., Maes, M. & Stuch, B. (2012a). Report on the second CLIMSAVE European stakeholder workshop. CLIMSAVE Deliverable 1.3a.
http://www.climsave.eu/climsave/doc/Report_on_the_second_European_workshop.pdf

Gramberger, M., Kok, K., Maes, M. & Stuch, B. (2012b). Report on the second CLIMSAVE regional stakeholder workshop. CLIMSAVE Deliverable 1.3b.
http://www.climsave.eu/climsave/doc/Report_on_the_second_regional_workshop.pdf

Gramberger, M., Harrison, P., Jäger, J., Kok, K., Libbrecht, S., Maes, M., Metzger, M., Stuch, B. & Watson, M. (2013a). Report on the third CLIMSAVE European stakeholder workshop. CLIMSAVE Deliverable 1.4a.
http://www.climsave.eu/climsave/doc/Report_on_the_third_European_workshop.pdf

Gramberger, M., Harrison, P., Jäger, J., Kok, K., Libbrecht, S., Maes, M., Metzger, M., Stuch, B. & Watson, M. (2013b). Report on the third CLIMSAVE regional stakeholder workshop. CLIMSAVE Deliverable 1.4b.
http://www.climsave.eu/climsave/doc/Report_on_the_third_regional_workshop.pdf

Harris, I., Jones, P.D., Osborn, T. J., Lister, D.H. (2014). Updated high-resolution grids of monthly climatic observations – the CRU TS.3.10 dataset. Int. Journal of Climatology, 34, 623-642.

Harrison PA, Holman IP, Berry PM (2014). Assessing cross-sectoral climate change impacts, vulnerability and adaptation: An Introduction to the CLIMSAVE project, Climatic Change, 128, 153-167.

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)]. Cambridge University Press, 996 pp.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Kok, K and JH Christensen (2014). IMPRESSIONS Scenario Methodology, IMPRESSIONS Living Document.

Kriegler, E., Edmonds, J., Hallegatte, S., Ebi, K.L., Kram, T., Riahi, K., Winkler, H. & Van Vuuren, D.P. (2014). A new scenario framework for climate change research: the concept of shared climate policy assumptions. Climatic Change, 122: 401-414.

MA (2005). Ecosystems and Human Well-being: Scenarios. Volume 2, Findings of the Scenarios Working Group of the Millennium Ecosystem Assessment. S.R. Carpenter, P.L. Pingali, E.M. Bennett, and M.B. Zurek, editors. Island Press, Washington, D.C. http://www.maweb.org/en/Products.Global.Scenarios.aspx.

Madsen, M.S., P.L. Langen, F. Boberg and J.H. Christensen (2015). Globally consistent patterns of regional climate change from ensembles of GCMs [In preparation].

Meehl, G.A. et al. (2007a). The WCRP CMIP3 multimodel dataset - A new era in climate change research. Bull. Am. Meteorol. Soc., 88, 1383-1394.

Meinshausen, M. et al. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Clim. Change, 109, 213-241.

Mitchell TD (2003). Pattern scaling. An examination of the accuracy of the technique for describing future climates. Clim. Change, 60: 217-242.

Mitchell T.D. and Jones, P.D. (2005). An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int. J. Climatology, 25, 693-712.

Moss, R.H. et al. (2008). Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies. In: IPCC Expert Meeting Report: Towards New Scenarios. Intergovernmental Panel on Climate Change, Geneva, Switzerland, 132 pp.

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: 747-756.

Nakićenović, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T. Y. Jung, T. Kram, E. Lebre La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H. -H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor & Z. Dadi (2000). Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. http://www.grida.no/climate/ipcc/emission/index.htm.

New, M., Lister, D., Hulme, M. and Makin, I. (2002). A high resolution data set of surface climate over global land areas. Climate Research, 21, 1-25.

Ngo-Duc, T., Polcher, T.and Laval, K. (2005). A 53-year forcing data set for land surface models. J. Geophys. Res. 110, D06116, doi:10.1029/2004JD005434.

O'Neill, B.C. and Schweizer, V. (2011). Projection and Prediction: Mapping the Road Ahead. News & Views article for Nature Climate Change, 1: 352-353.

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R. & Van Vuuren, D.P. (2014). A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Climatic Change, 122: 387-400.

O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., Van Ruijven, B.J., Van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M. & Solecki, W. (2015). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change. Accepted. http://dx.doi.org/10.1016/j.gloenvcha.2015.01.004.

Räty O., Räisänen, J., Ylhäisi, J.S. (2014). Evaluation of delta change and bias correction methods for future daily precipitation: intermodel cross-validation using ENSEMBLES simulations.

Rothman, D.S. (2008). A survey of environmental scenarios. In: Alcamo, J. (Ed.), Environmental futures: the practice of environmental scenario analysis. Developments in Integrated Environmental Assessment – Volume 2. Elsevier, Amsterdam, pp. 37-65.

Santer BD, Wigley TML, Schlesinger ME, Mitchell JFB (1990). Developing climate scenarios from equilibrium GCM results. Report No.47, Max Planck Institute für Meteorologie, Hamburg.

Shell. (2008). Shell energy scenarios to 2050. Shell International BV.

Taylor, K.E., R.J. Stouffer and G.A. Meehl (2012). A summary of the CMIP5 experiment design. Bull. Am. Meteorol. Soc., 93, 485-498.

Taylor, K.E., Stouffer, R.J. and Meehl, G.A. (2012). A summary of the CMIP5 experiment design. Bulletin of the American Meteorological Society, 93: 485-498.

UNEP (2002). Global Environment Outlook 3: Past, present and future perspectives. United Nations Environment Programme, Nairobi.

UNEP (2007). Global Environment Outlook 4. United Nations Environment Programme, Nairobi.

van der Linden P, Mitchell JFB (eds) (2009). ENSEMBLES: climate change and its impacts. Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, Exeter

van Vuuren, D.P. et al. (2011). RCP3–PD: Exploring the possibilities to limit global mean temperature change to less than 2°C. Clim. Change, 109, 95-116.

Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M.,Nakicenovic, N., Smith, S.J. & Rose, S.K. (2011). The representative concentration pathways: an overview. Climatic Change, 109: 5-31.

Vautard R, Gobiet A, Sobolowski S, Kjellström E, Stegehuis A, Watkiss P, Mendlik T, Landgren O, Nikulin G, Teichmann C, & Jacob D (2014). The European climate under a 2°C warming. Environmental Research Letters, 9, DOI 10.1088/1748-9326/9/3/034006.

Weedon, G.P., Balsamo, G., Bellouin, N., Gomes, S., Best, M.J. and Viterbo, P. (2014). The WFDEI meteorological forcing data set: WATCH Forcing data methodology applied to ERA-Interim reanalysis data. *Water Resources Research*, 50, doi:10.1002/2014WR015638.

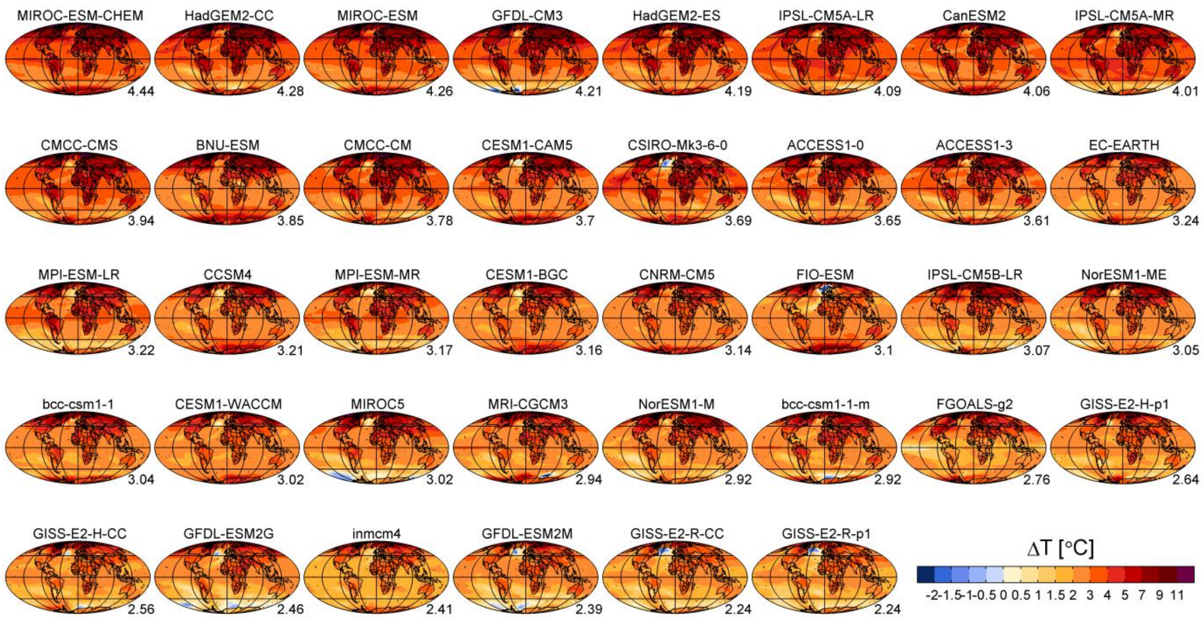
Westhoek, H.J., Van den Berg, M. and Bakkes, J.A. (2006). Scenario development to explore the future of Europe's rural areas. Agriculture, Ecosystems and Environment, 114: 7-20.

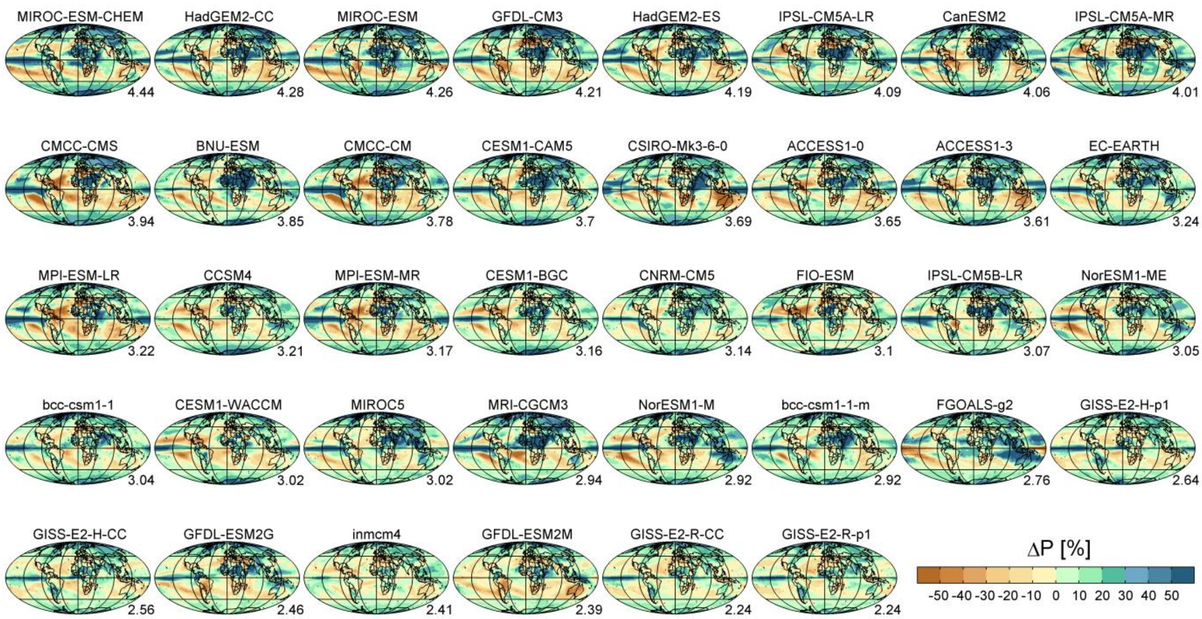
Zurek, M.B. (2006). A short review of global scenarios for food systems analysis. GECAFS Working Paper 1. ESAC, FAO, Rome.

Annex A: CMIP5 and CORDEX models

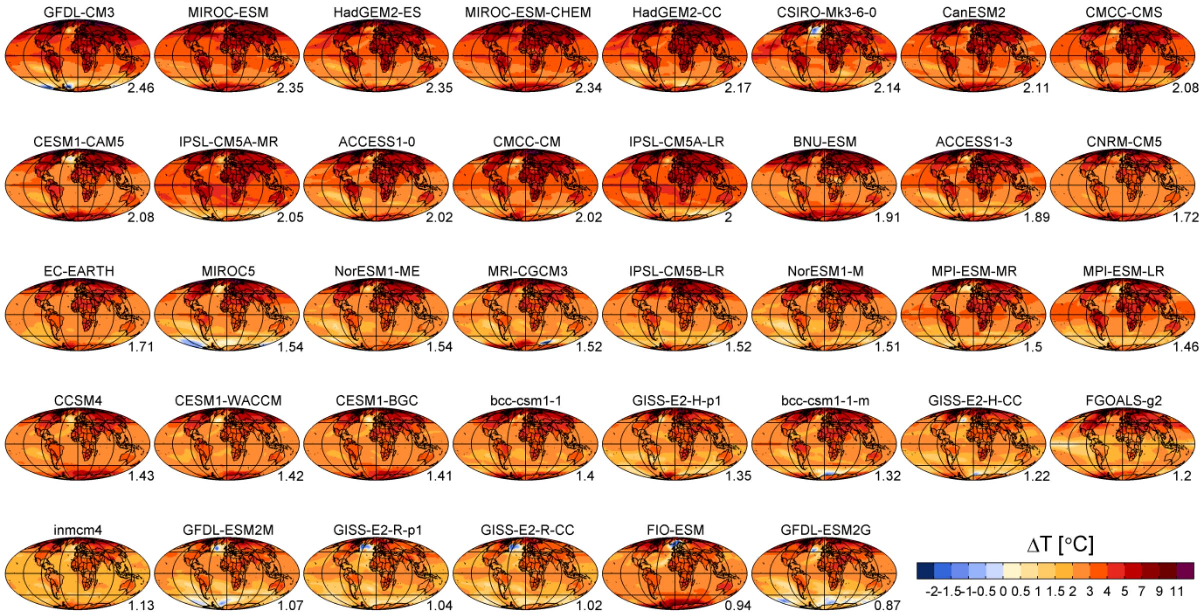
The following maps show GCM models annual mean temperature and precipitation change 2071-2100 vs. 1981-2010 for RCP8.5 and RCP4.5. Ranking is according to global mean temperature change, which denotes each subfigure. Note that order differs between RCP8.5 and RCP4.5.

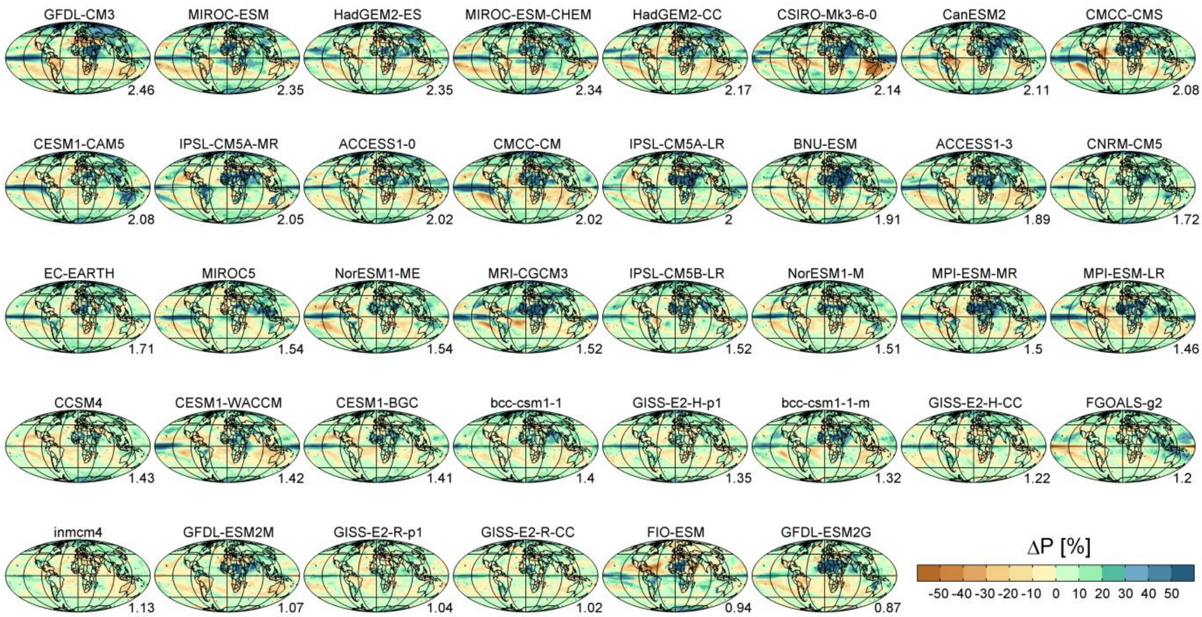
RCP8.5





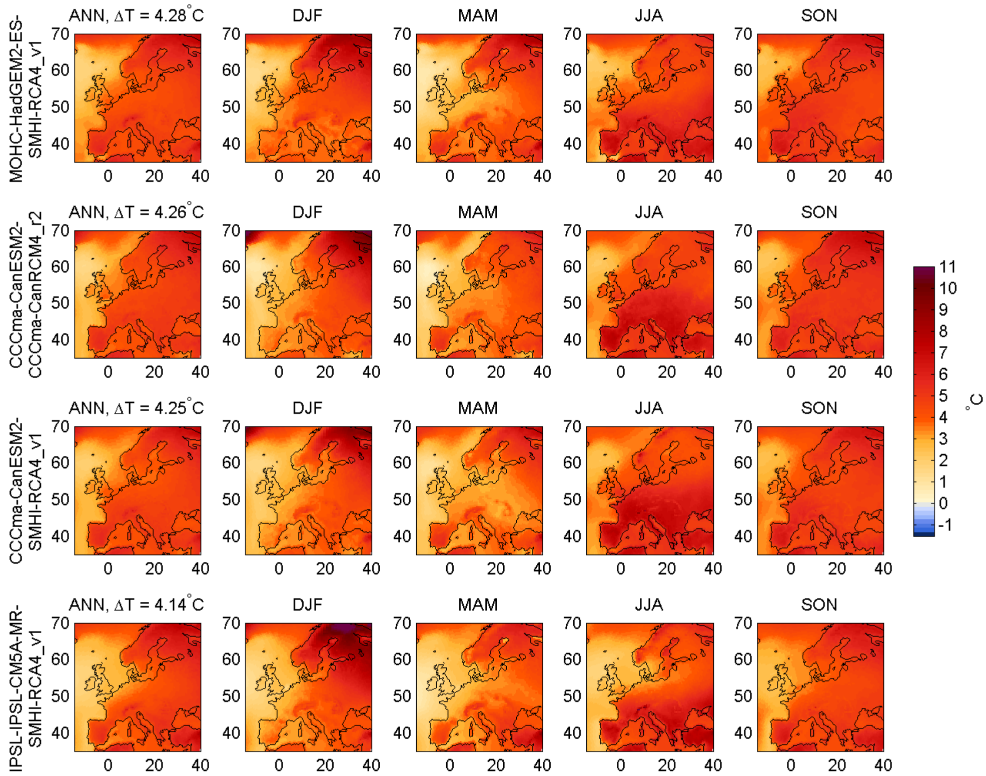
RCP4.5

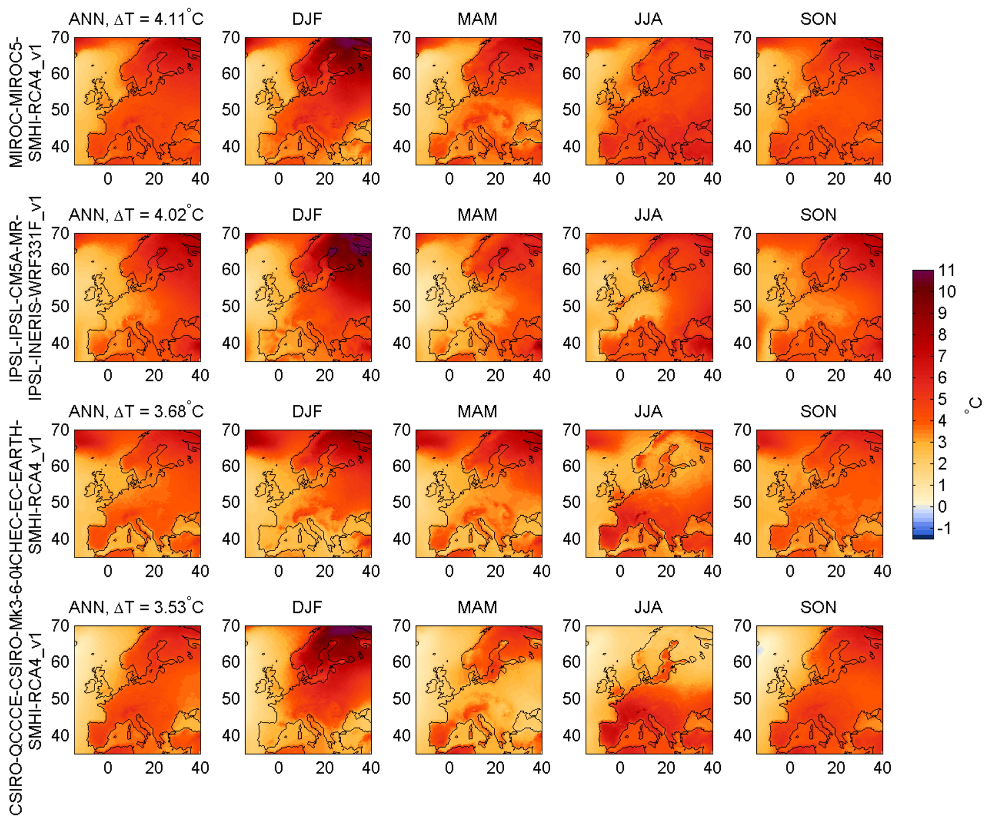

GFDL-CM3 2.46
MIROC-ESM 2.35
HadGEM2-ES 2.35
MIROC-ESM-CHEM 2.34
HadGEM2-CC 2.17
CSIRO-Mk3-6-0 2.14
CanESM2 2.11
CMCC-CMS 2.08
CESM1-CAM5 2.08
IPSL-CM5A-MR 2.05
ACCESS1-0 2.02
CMCC-CM 2.02
IPSL-CM5A-LR 2
BNU-ESM 1.91
ACCESS1-3 1.89
CNRM-CM5 1.72
EC-EARTH 1.71
MIROC5 1.54
NorESM1-ME 1.54
MRI-CGCM3 1.52
IPSL-CM5B-LR 1.52
NorESM1-M 1.51
MPI-ESM-MR 1.5
MPI-ESM-LR 1.46
CCSM4 1.43
CESM1-WACCM 1.42
CESM1-BGC 1.41
bcc-csm1-1 1.4
GISS-E2-H-p1 1.35
bcc-csm1-1-m 1.32
GISS-E2-H-CC 1.22
FGOALS-g2 1.2
inmcm4 1.13
GFDL-ESM2M 1.07
GISS-E2-R-p1 1.04
GISS-E2-R-CC 1.02
FIO-ESM 0.94
GFDL-ESM2G 0.87
ΔT [°C]
-2 -1.5 -1 -0.5 0 0 0.5 1 1.5 2 3 4 5 7 9 11

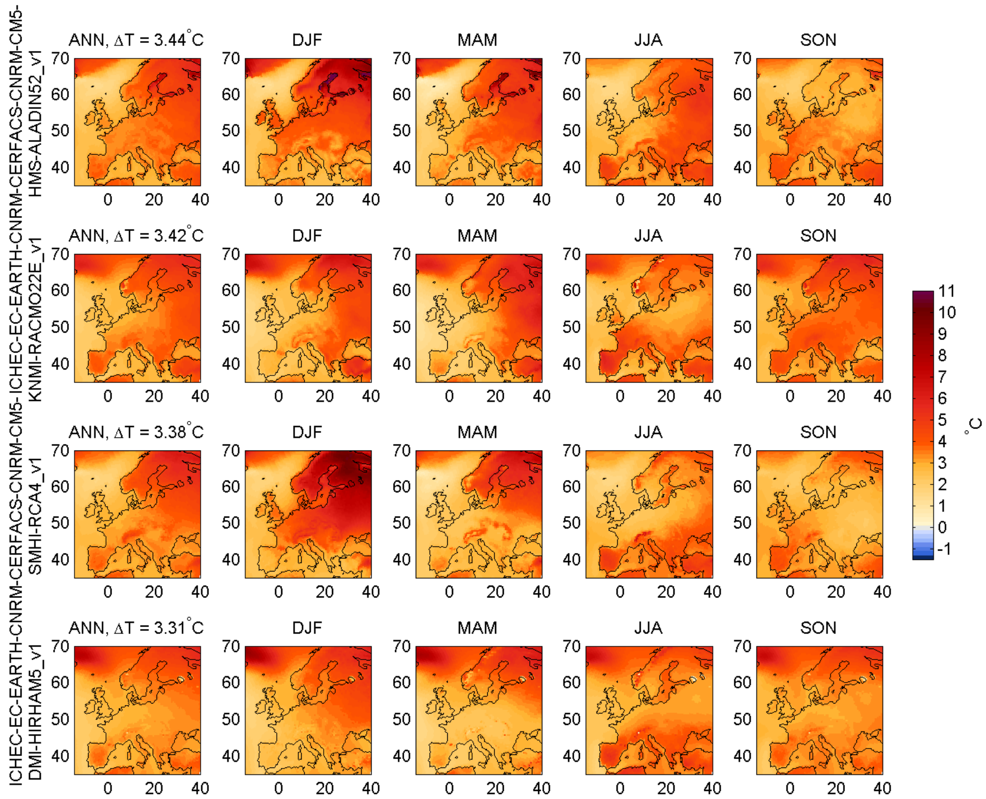

GFDL-CM3 2.46
MIROC-ESM 2.35
HadGEM2-ES 2.35
MIROC-ESM-CHEM 2.34
HadGEM2-CC 2.17
CSIRO-Mk3-6-0 2.14
CanESM2 2.11
CMCC-CMS 2.08
CESM1-CAM5 2.08
IPSL-CM5A-MR 2.05
ACCESS1-0 2.02
CMCC-CM 2.02
IPSL-CM5A-LR 2
BNU-ESM 1.91
ACCESS1-3 1.89
CNRM-CM5 1.72
EC-EARTH 1.71
MIROC5 1.54
NorESM1-ME 1.54
MRI-CGCM3 1.52
IPSL-CM5B-LR 1.52
NorESM1-M 1.51
MPI-ESM-MR 1.5
MPI-ESM-LR 1.46
CCSM4 1.43
CESM1-WACCM 1.42
CESM1-BGC 1.41
bcc-csm1-1 1.4
GISS-E2-H-p1 1.35
bcc-csm1-1-m 1.32
GISS-E2-H-CC 1.22
FGOALS-g2 1.2
inmcm4 1.13
GFDL-ESM2M 1.07
GISS-E2-R-p1 1.04
GISS-E2-R-CC 1.02
FIO-ESM 0.94
GFDL-ESM2G 0.87
ΔP [%]
-50 -40 -30 -20 -10 0 10 20 30 40 50

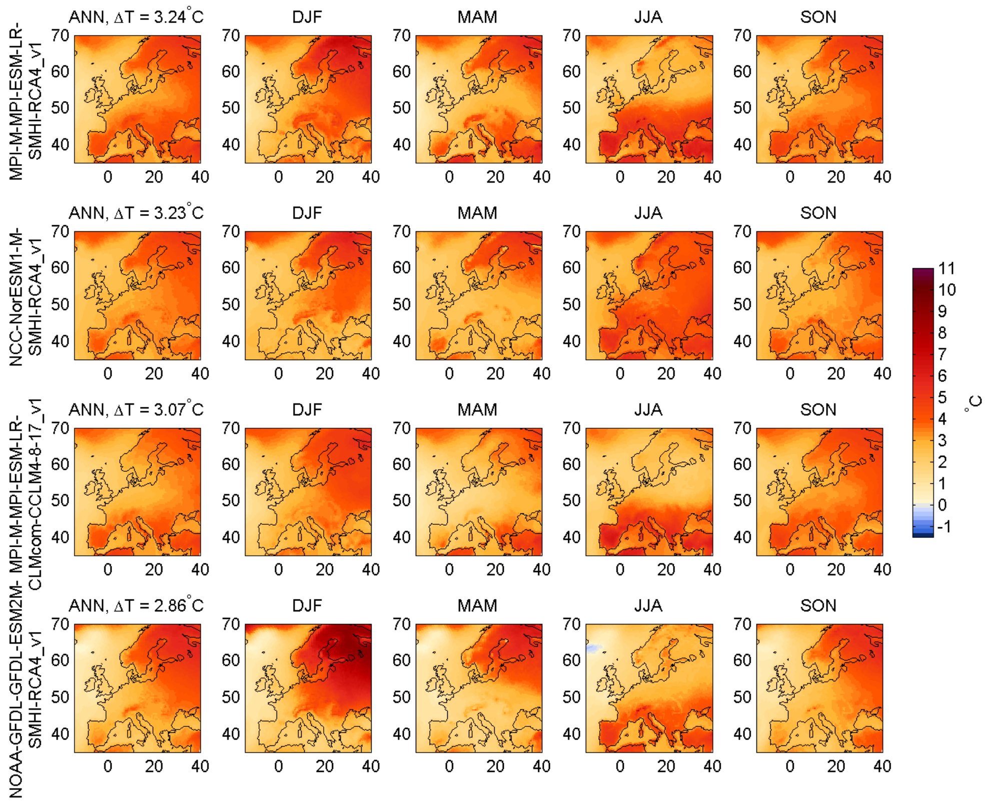
The following maps show annual mean temperature and precipitation change over Europe (2071-2010 vs. 1981-2010) for RCP4.5 and RCP8.5 for the GCM/RCM combinations available from the CORDEX archive. The annual mean change in temperature is shown in the upper left corner of the temperature plots. The models are ranked according to the RCP8.5 temperature change and the same order of appearance is given for RCP4.5 and for both precipitation series of maps. It is the intention to produce a scientific paper that reports on these following closely what was presented in Christensen & Christensen (2007) for the PRUDENCE project.

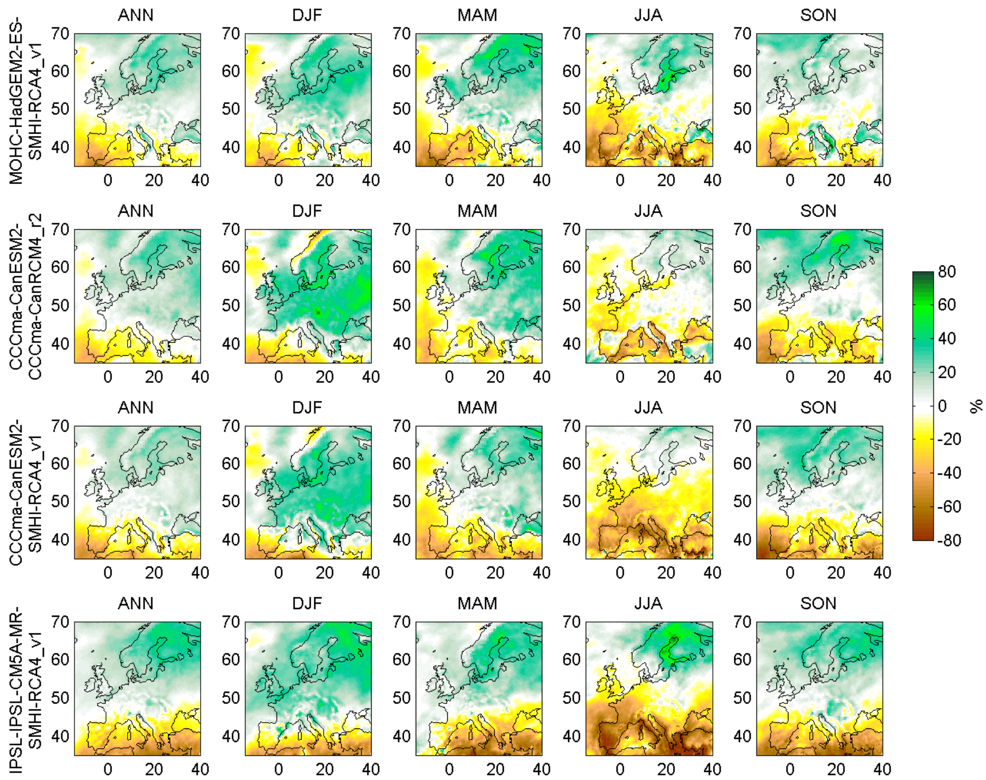
RCP8.5

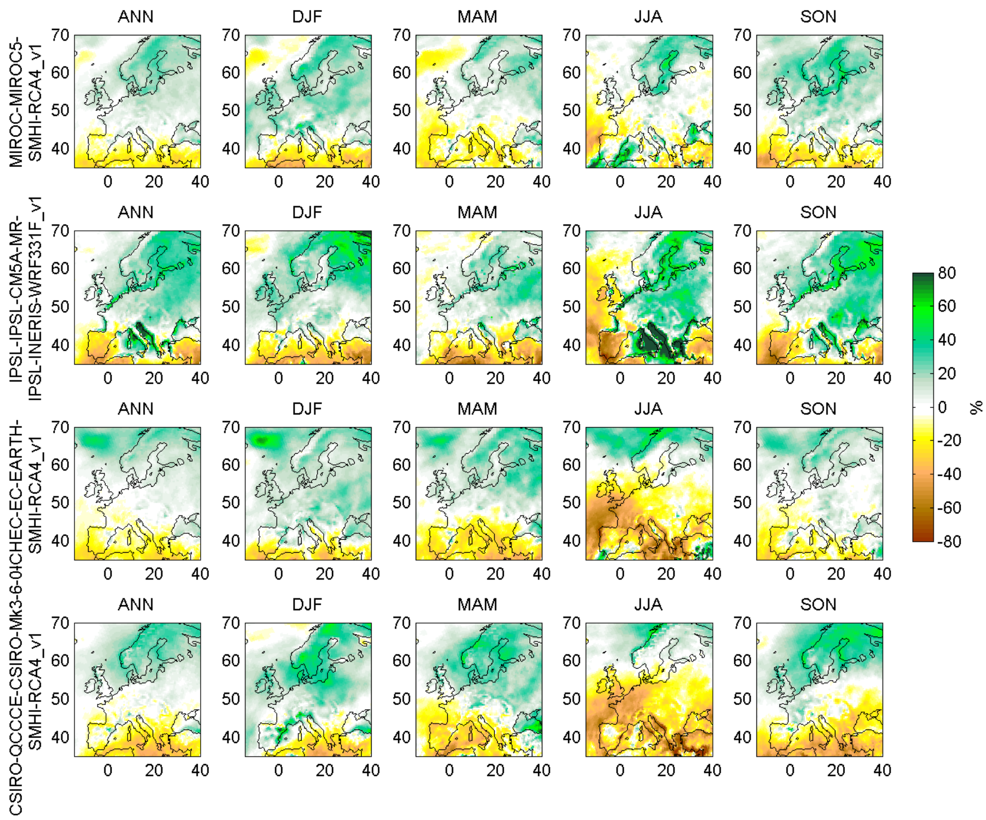

MOHC-HadGEM2-ES-SMHI-RCA4_v1
ANN, ΔT = 4.28°C
CCCma-CanESM2-CCCma-CanRCM4_r2
ANN, ΔT = 4.26°C
CCCma-CanESM2-SMHI-RCA4_v1
ANN, ΔT = 4.25°C
IPSL-IPSL-CM5A-MR-SMHI-RCA4_v1
ANN, ΔT = 4.14°C
DJF
MAM
JJA
SON
°C

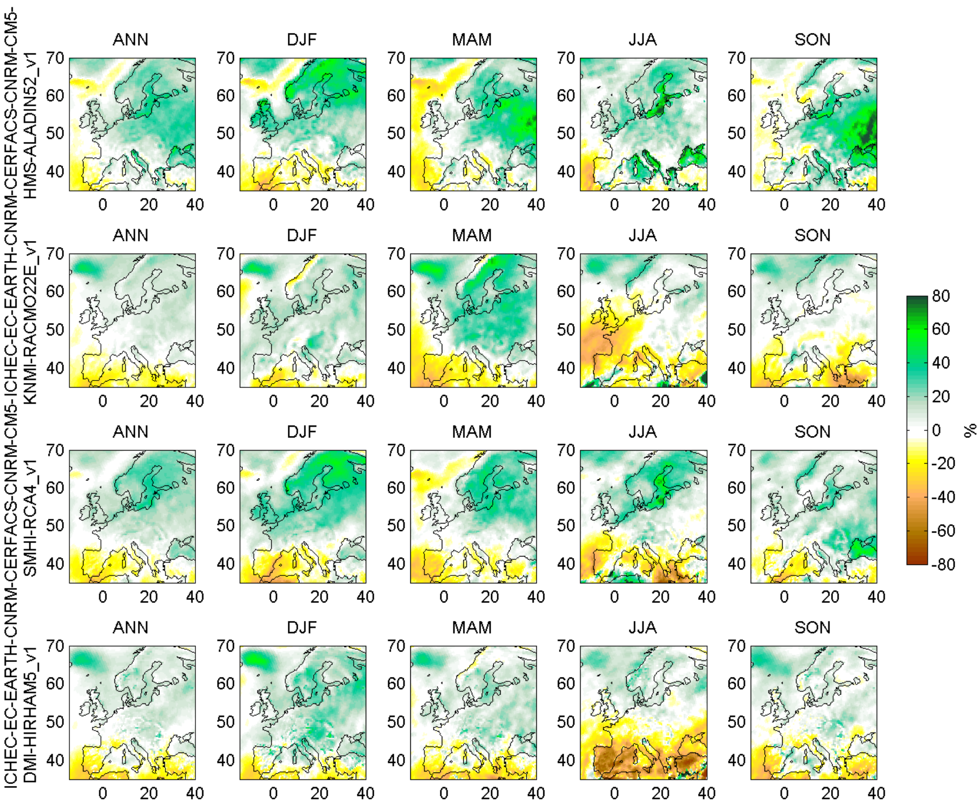

MIROC-MIROC5-SMHI-RCA4_v1
ANN, ΔT = 4.11°C
IPSL-IPSL-CM5A-MR-IPSL-INERIS-WRF331F_v1
ANN, ΔT = 4.02°C
ICHEC-EC-EARTH-SMHI-RCA4_v1
ANN, ΔT = 3.68°C
CSIRO-QCCCE-CSIRO-Mk3-6-0-SMHI-RCA4_v1
ANN, ΔT = 3.53°C
DJF
MAM
JJA
SON
°C

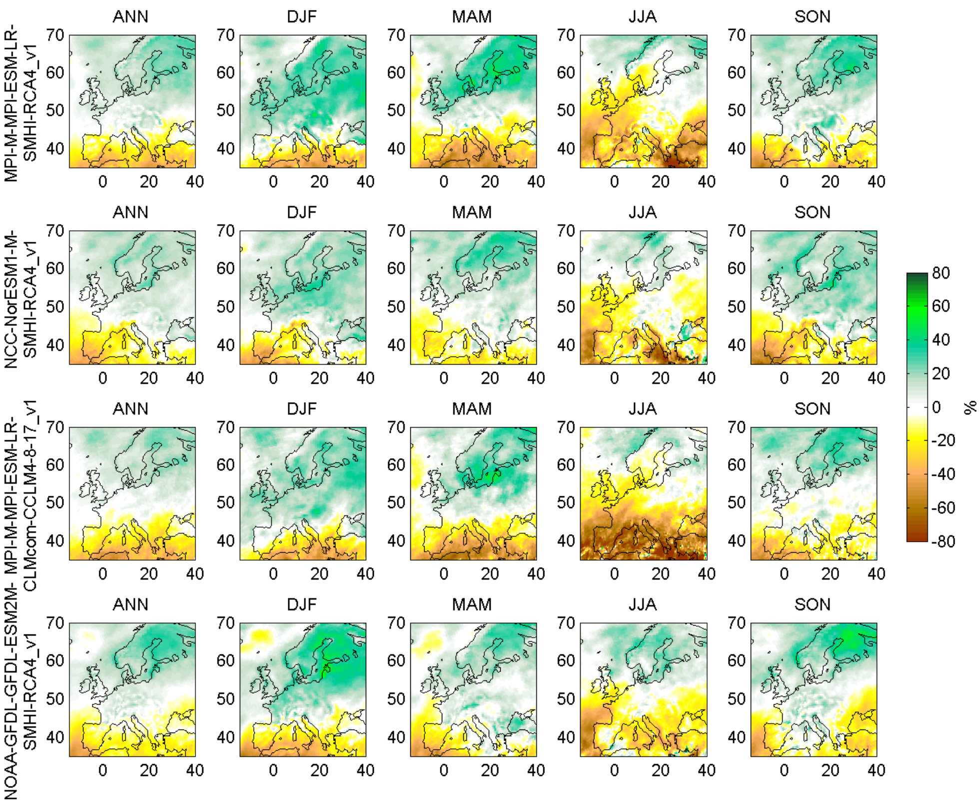

CNRM-CERFACS-CNRM-CM5-HMS-ALADIN52_v1
ICHEC-EC-EARTH-KNMI-RACMO22E_v1
CNRM-CERFACS-CNRM-CM5-SMHI-RCA4_v1
ICHEC-EC-EARTH-DMI-HIRHAM5_v1
ANN, ΔT = 3.44°C
ANN, ΔT = 3.42°C
ANN, ΔT = 3.38°C
ANN, ΔT = 3.31°C
DJF
MAM
JJA
SON
°C


MPI-M-MPI-ESM-LR-SMHI-RCA4_v1
NCC-NorESM1-M-SMHI-RCA4_v1
MPI-M-MPI-ESM-LR-CLMcom-CCLM4-8-17_v1
NOAA-GFDL-GFDL-ESM2M-SMHI-RCA4_v1
ANN, ΔT = 3.24°C
ANN, ΔT = 3.23°C
ANN, ΔT = 3.07°C
ANN, ΔT = 2.86°C
DJF
MAM
JJA
SON
°C

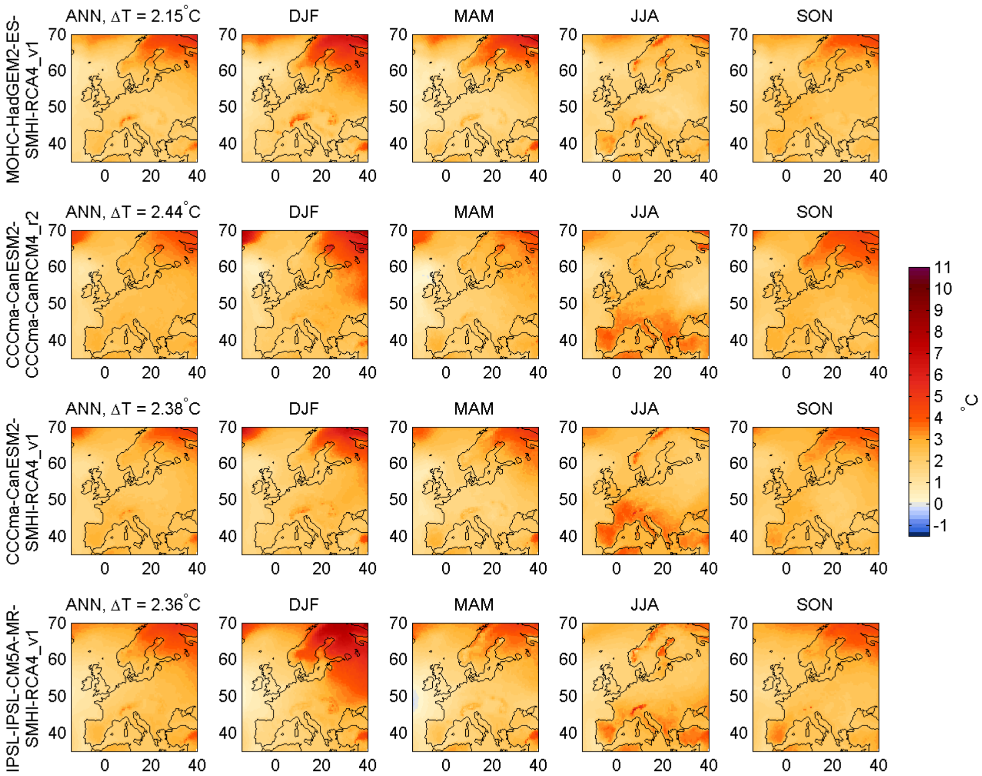

ANN
DJF
MAM
JJA
SON
MOHC-HadGEM2-ES-SMHI-RCA4_v1
CCCma-CanESM2-CCCma-CanRCM4_r2
CCCma-CanESM2-SMHI-RCA4_v1
IPSL-IPSL-CM5A-MR-SMHI-RCA4_v1
%

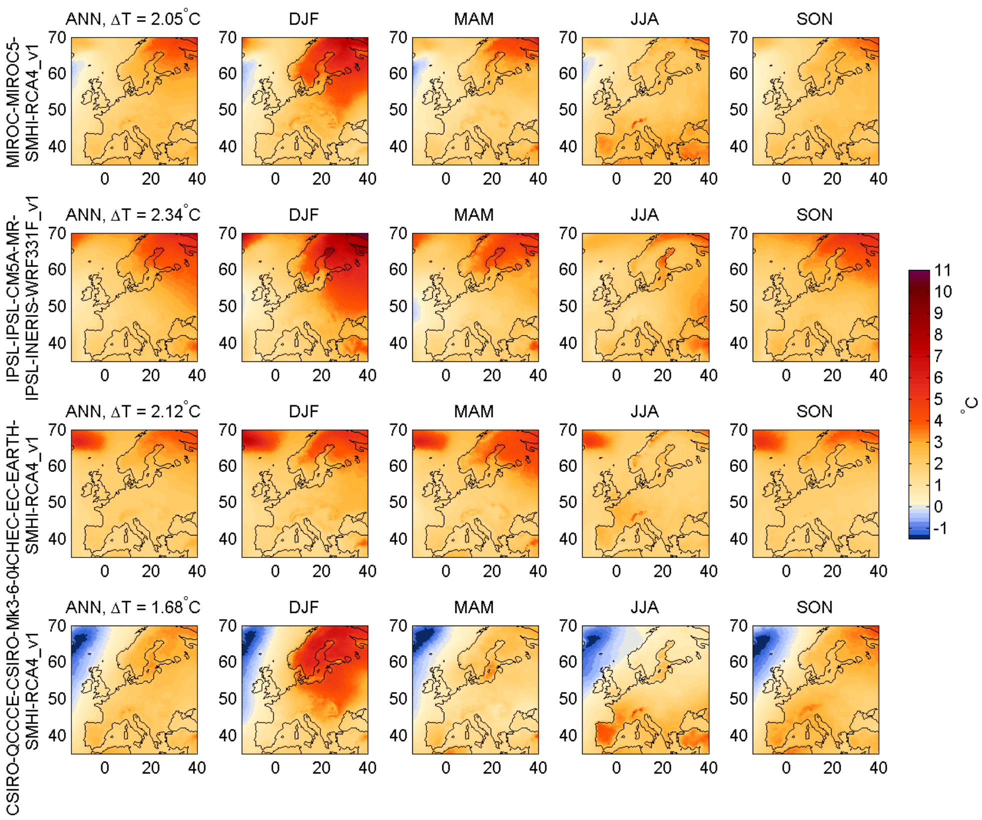

ANN
DJF
MAM
JJA
SON
MIROC-MIROC5-SMHI-RCA4_v1
IPSL-IPSL-CM5A-MR-IPSL-INERIS-WRF331F_v1
ICHEC-EC-EARTH-SMHI-RCA4_v1
CSIRO-QCCCE-CSIRO-Mk3-6-0-SMHI-RCA4_v1
%

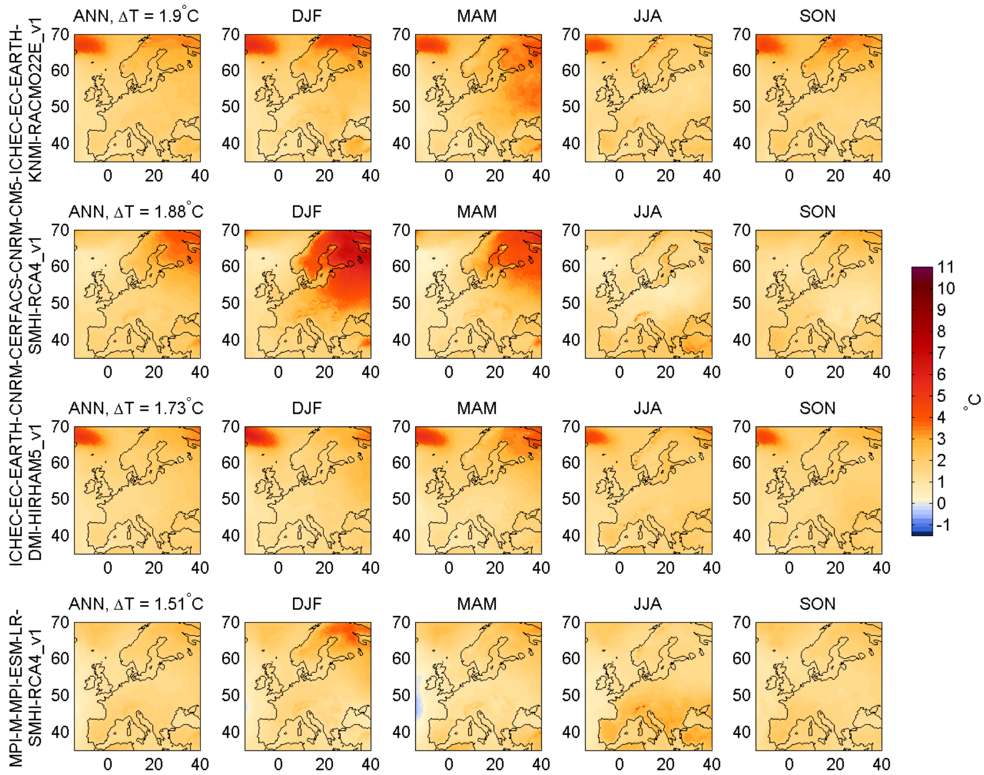

CNRM-CERFACS-CNRM-CM5-
HMS-ALADIN52_v1
ICHEC-EC-EARTH-
KNMI-RACMO22E_v1
CNRM-CERFACS-CNRM-CM5-
SMHI-RCA4_v1
ICHEC-EC-EARTH-
DMI-HIRHAM5_v1
ANN
DJF
MAM
JJA
SON
70
60
50
40
0
20
40
80
60
40
20
0
-20
-40
-60
-80
%

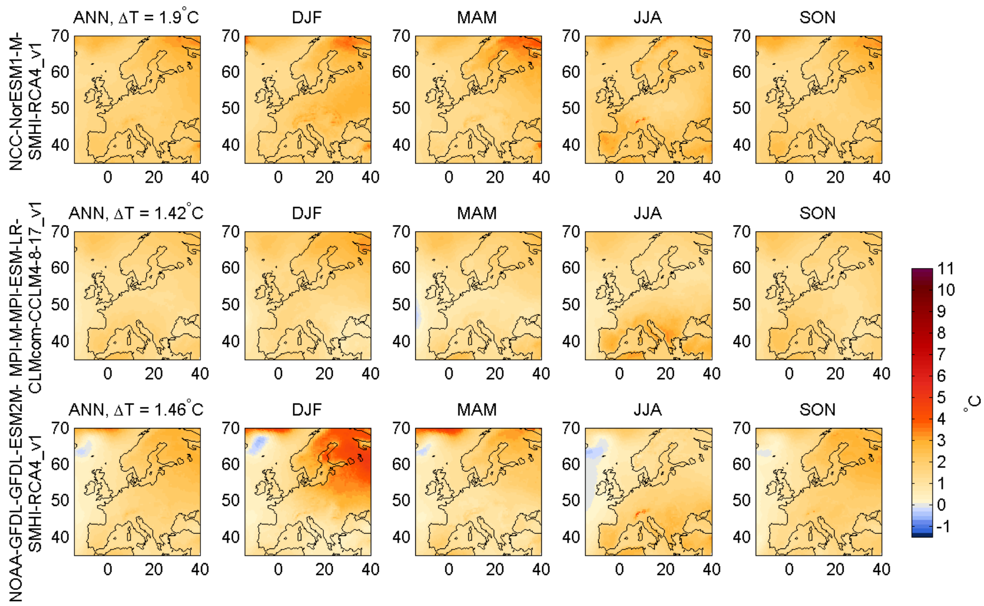

MPI-M-MPI-ESM-LR-
SMHI-RCA4_v1
NCC-NorESM1-M-
SMHI-RCA4_v1
MPI-M-MPI-ESM-LR-
CLMcom-CCLM4-8-17_v1
NOAA-GFDL-GFDL-ESM2M-
SMHI-RCA4_v1
ANN
DJF
MAM
JJA
SON
70
60
50
40
0
20
40
80
60
40
20
0
-20
-40
-60
-80
%

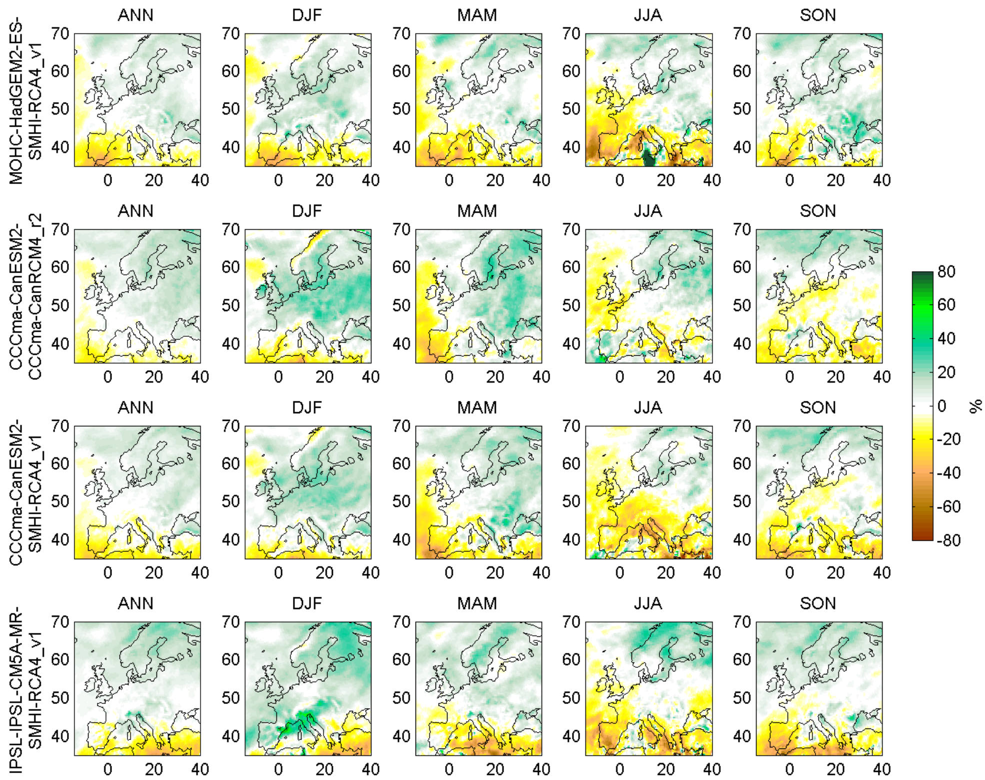
RCP4.5

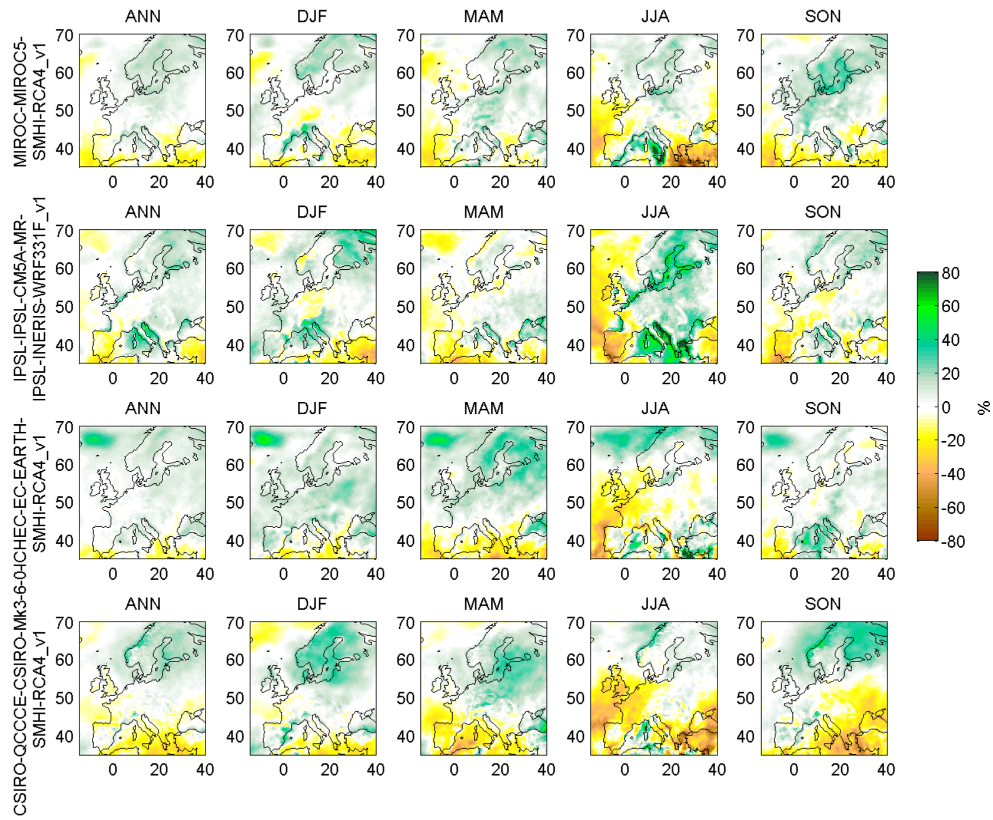

MOHC-HadGEM2-ES-
SMHI-RCA4_v1
ANN, ΔT = 2.15°C
CCCma-CanESM2-
CCCma-CanRCM4_r2
ANN, ΔT = 2.44°C
CCCma-CanESM2-
SMHI-RCA4_v1
ANN, ΔT = 2.38°C
IPSL-IPSL-CM5A-MR-
SMHI-RCA4_v1
ANN, ΔT = 2.36°C
DJF
MAM
JJA
SON
°C

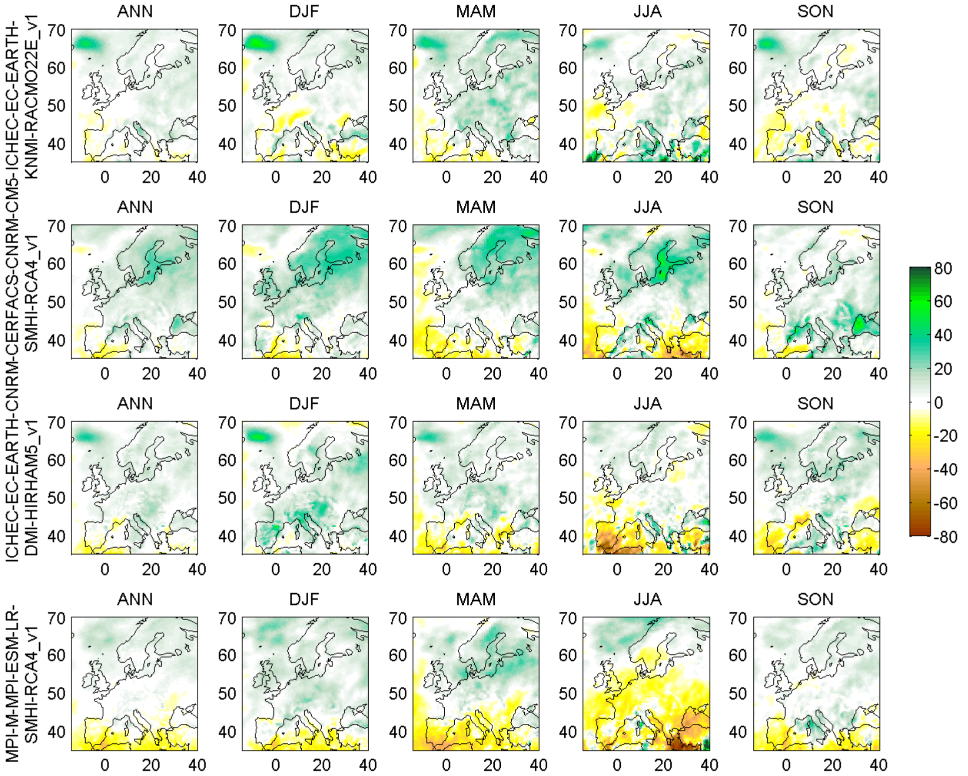

MIROC-MIROC5-
SMHI-RCA4_v1
ANN, ΔT = 2.05°C
IPSL-IPSL-CM5A-MR-
IPSL-INERIS-WRF331F_v1
ANN, ΔT = 2.34°C
ICHEC-EC-EARTH-
SMHI-RCA4_v1
ANN, ΔT = 2.12°C
CSIRO-QCCCE-CSIRO-Mk3-6-0-
SMHI-RCA4_v1
ANN, ΔT = 1.68°C
DJF
MAM
JJA
SON
°C

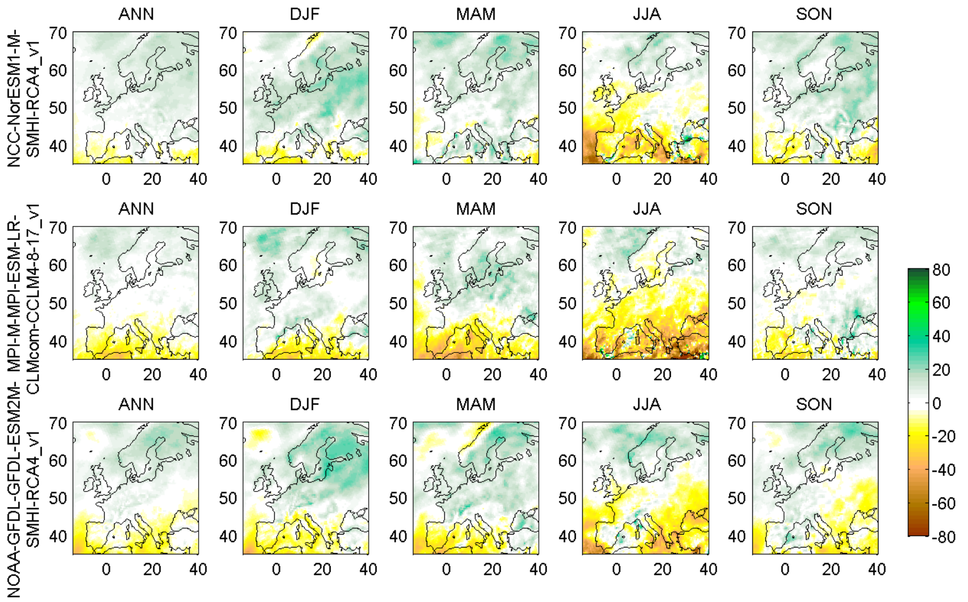

ICHEC-EC-EARTH-KNMI-RACMO22E_v1
CNRM-CERFACS-CNRM-CM5-SMHI-RCA4_v1
ICHEC-EC-EARTH-DMI-HIRHAM5_v1
MPI-M-MPI-ESM-LR-SMHI-RCA4_v1
ANN, ΔT = 1.9°C
ANN, ΔT = 1.88°C
ANN, ΔT = 1.73°C
ANN, ΔT = 1.51°C
DJF
MAM
JJA
SON
°C


NCC-NorESM1-M-SMHI-RCA4_v1
MPI-M-MPI-ESM-LR-CLMcom-CCLM4-8-17_v1
NOAA-GFDL-GFDL-ESM2M-SMHI-RCA4_v1
ANN, ΔT = 1.9°C
ANN, ΔT = 1.42°C
ANN, ΔT = 1.46°C
DJF
MAM
JJA
SON
°C


ANN
DJF
MAM
JJA
SON
MOHC-HadGEM2-ES-SMHI-RCA4_v1
CCCma-CanESM2-CCCma-CanRCM4_r2
CCCma-CanESM2-SMHI-RCA4_v1
IPSL-IPSL-CM5A-MR-SMHI-RCA4_v1
80
60
40
20
0
-20
-40
-60
-80
%


ANN
DJF
MAM
JJA
SON
MIROC-MIROC5-SMHI-RCA4_v1
IPSL-IPSL-CM5A-MR-IPSL-INERIS-WRF331F_v1
ICHEC-EC-EARTH-SMHI-RCA4_v1
CSIRO-QCCCE-CSIRO-Mk3-6-0-SMHI-RCA4_v1
80
60
40
20
0
-20
-40
-60
-80
%


ANN
DJF
MAM
JJA
SON
ICHEC-EC-EARTH-
KNMI-RACMO22E_v1
CNRM-CERFACS-CNRM-CM5-
SMHI-RCA4_v1
ICHEC-EC-EARTH-
DMI-HIRHAM5_v1
MPI-M-MPI-ESM-LR-
SMHI-RCA4_v1
80
60
40
20
0
-20
-40
-60
-80
%


ANN
DJF
MAM
JJA
SON
NCC-NorESM1-M-
SMHI-RCA4_v1
MPI-M-MPI-ESM-LR-
CLMcom-CCLM4-8-17_v1
NOAA-GFDL-GFDL-ESM2M-
SMHI-RCA4_v1
80
60
40
20
0
-20
-40
-60
-80
%

Annex B: Full versions of the narratives of the SSPs

SSP1: Sustainability – taking the green road

The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift. Management of the global commons slowly improves, facilitated by increasingly effective and persistent cooperation and collaboration of local, national, and international organizations and institutions, the private sector, and civil society. Educational and health investments accelerate the demographic transition, leading to a relatively low population. Beginning with current high-income countries, the emphasis on economic growth shifts toward a broader emphasis on human well-being, even at the expense of somewhat slower economic growth over the longer term. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Investment in environmental technology and changes in tax structures lead to improved resource efficiency, reducing overall energy and resource use and improving environmental conditions over the longer term. Increased investment, financial incentives and changing perceptions make renewable energy more attractive. Consumption is oriented toward low material growth and lower resource and energy intensity. The combination of directed development of environmentally friendly technologies, a favourable outlook for renewable energy, institutions that can facilitate international cooperation, and relatively low energy demand results in relatively low challenges to mitigation. At the same time, the improvements in human well-being, along with strong and flexible global, regional, and national institutions imply low challenges to adaptation.

SSP3: Regional Rivalry – a rocky road

Growing interest in regional identity, regional conflicts, and concerns about competitiveness and security push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns. Policies shift over time to become increasingly oriented toward national and regional security issues, including barriers to trade, particularly in the energy resource and agricultural markets. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development, and in several regions move toward more authoritarian forms of government with highly regulated economies. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time, especially in developing countries. There are pockets of extreme poverty alongside pockets of moderate wealth, with many countries struggling to maintain living standards and provide access to safe water, improved sanitation, and health care for disadvantaged populations. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions. The combination of impeded development and limited environmental concern results in poor progress toward sustainability. Population growth is low in industrialized and high in developing countries. Growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change imply high challenges to mitigation. The limited progress on human development, slow income growth, and lack of effective institutions, especially those that can act across regions, implies high challenges to adaptation for many groups in all regions.

SSP4: Inequality – a road divided

Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labour intensive, low-tech economy. Power becomes more concentrated in a relatively small political and business elite, even in democratic societies, while vulnerable groups have little representation in national and global institutions. Economic growth is moderate in industrialized and middle-income countries, while low income countries lag behind, in many cases struggling to provide adequate access to water, sanitation and health care for the poor. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. Uncertainty in the fossil fuel markets lead to underinvestment in new resources in many regions of the world. Oil and gas prices rise and volatility increases. Energy companies hedge against price fluctuations partly through diversifying their energy sources, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas. The combination of some development of low carbon supply options and expertise, and a well-integrated international political and business class capable of acting quickly and decisively, implies low challenges to mitigation. Challenges to adaptation are high for the substantial proportions of populations at low levels of development and with limited access to effective institutions for coping with economic or environmental stresses.

SSP5: Fossil-fueled Development – Taking the highway

Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary. While local environmental impacts are addressed effectively by technological solutions, there is relatively little effort to avoid potential global environmental impacts due to a perceived trade-off with progress on economic development. Global population peaks and declines in the 21st century. Though fertility declines rapidly in developing countries, fertility levels in high income countries are relatively high (at or above replacement level) due to optimistic economic outlooks. International mobility is increased by gradually opening up labour markets as income disparities decrease. The strong reliance on fossil fuels and the lack of global environmental concern result in potentially high challenges to mitigation. The attainment of human development goals, robust economic growth, and highly engineered infrastructure results in relatively low challenges to adaptation to any potential climate change for all but a few.