INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

IPCC Workshop on Socio-Economic Scenarios

Victor's Residenz-Hotel
Berlin, Germany
1-3 November 2010

Workshop Report

Edited by:
Ottmar Edenhofer, Ramón Pichs-Madruga, Youba Sokona
Vicente Barros, Christopher B. Field
Timm Zwickel, Steffen Schlömer, Kristie Ebi, Michael Mastrandrea,
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Cover photo courtesy of Benjamin Kriemann, Berlin, Germany

ISBN 978-92-9169-7

Published May 2012 by the IPCC Working Group III Technical Support Unit, Potsdam Institute for Climate Impact Research, Potsdam, Germany. Electronic copies of this report are available from the IPCC website (ipcc.ch) and the IPCC WGIII website (ipcc-wg3.de).

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This Workshop Report should be cited as:

IPCC, 2012: *Workshop Report of the Intergovernmental Panel on Climate Change Workshop on Socio-Economic Scenarios* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, V. Barros, C.B. Field, T. Zwickel, S. Schloemer, K. Ebi, M. Mastrandrea, K. Mach, C. von Stechow (eds.)]. IPCC Working Group III Technical Support Unit, Potsdam Institute for Climate Impact Research, Potsdam Germany, pp. 51.

Preface

An important goal of the upcoming 5th IPCC Assessment Report (AR5) will be improved coherence across the three IPCC Working Groups. Helping to achieve this goal, the IPCC Workshop on Socioeconomic Scenarios for Climate Change Impact and Response Assessment (WoSES) that took place in **Berlin, Germany (1-3 November, 2010),** contributed significantly to the process of facilitating the development of new scenarios that will be used for the assessment of projected climate change and its impacts, the degree to which adaptation and mitigation policies could reduce changes and impacts, and the costs of action and inaction. The third phase of the new scenario process – the development of socioeconomic pathways and narratives by the integrated assessment modelling, impacts, and adaptation communities – was advanced during WoSES. Development of these pathways and narratives will enable the AR5 to analyze the interdependent issues of adaptation *and* mitigation in an integrated manner.

The scientific core of this workshop report briefly summarizes the outcomes and conclusions of WoSES. It contains a stand-alone paper (Annex I) initiated during the workshop that was widely circulated to the relevant scientific communities for feedback and will be submitted for publication in a peer-reviewed journal in the coming months. This framework paper will serve as a reference document for the integrated assessment modelling, impacts, and adaptation communities in their ongoing research feeding into the AR5, particularly of Working Groups II and III. This workshop report also includes the Workshop Programme and the Participant List.

We extend our sincere gratitude to the German IPCC-Coordination Office for sponsoring and hosting the meeting and for the excellent arrangements. We also thank the members of the Scientific Steering Committee who provided invaluable advice on the invitees and planning of the meeting as well as help to carry out the programme. We would like to thank all participants who contributed to very constructive and fruitful discussions, where exchanging views and knowledge resulted in more clarity on the issues involved and the current status of scientific understanding. In particular, the members of the core writing team put in many hours of effort following the workshop to produce the draft framework paper in a timely fashion, and we are deeply grateful.

This workshop highlighted again that a structured and consistent assessment of possible future vulnerabilities, impacts, adaptation, and mitigation would benefit from using shared qualitative narrative and quantitative descriptions of potential socioeconomic and ecosystem reference conditions that underlie challenges to mitigation and adaptation. We believe that this workshop helped the different communities to pursue a process that will be an important input to the AR5 and beyond.

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Outline and Outcome of IPCC Workshop on Socio-Economic Scenarios

The IPCC 5th Assessment Report (AR5) will feature assessments of projected climate change and its impacts, the degree to which adaptation and mitigation policies could reduce changes and impacts, and the costs of action and inaction using new scenarios, as laid out in the IPCC Expert Meeting on scenarios in Noordwijkerhout, Netherlands (19-21 September 2007). The process for developing new scenarios includes a preparatory phase that identified Representative Concentration Pathways (RCPs) of the basket of greenhouse gases and associated levels of radiative forcing. In the second phase, the earth system modelling community is performing model ensemble runs and pattern scaling analyses based on emission pathways developed by integrated assessment models to be consistent with the RCPs. The results of these experiments will be available soon. The third phase will develop qualitative and quantitative socioeconomic narratives that can be used with the RCPs to create scenarios of future worlds. The goal of the IPCC Workshop on Socio-Economic Scenarios (WoSES) was to facilitate the development of these socioeconomic narratives and pathways by the integrated assessment modelling, impacts, and adaptation communities. Describing these pathways and narratives is a core step to analyzing the interdependent issues of adaptation and mitigation in an integrated manner.

The workshop included 99 participants, consisting of invited experts; Working Group II and III AR5 Coordinating Lead Authors, Lead Authors, and Review Editors; Working Group II and III Co-Chairs and Bureau members; IPCC officials (including the IPCC Chair and Secretary); and Working Group II and III TSU staff. Annex II provides the Workshop Programme and Annex III lists the Workshop Participants.

The Workshop established a writing team composed of members of the integrated assessment, impacts, and adaptation scientific communities to refine and further develop the discussions and agreements in a paper "A framework for a new generation of socio-economic scenarios for climate change impact, adaptation, vulnerability, and mitigation research". The writing team Coordinating Lead Authors are Tom Kram and Nigel Arnell, with Lead Authors Timothy Carter, Kristie Ebi, Jae Edmonds, Stéphane Hallgatte, Elmar Kriegler, Ritu Mathur, Brian O'Neill, Keywan Riahi, Harald Winkler, Detlef van Vuuren, Timm Zwickel. The latest draft of this paper is presented in Annex I.

The Workshop participants agreed that structured and consistent assessments of possible future impacts, vulnerabilities, adaptation, and mitigation would benefit from using shared qualitative narrative and quantitative descriptions of potential socioeconomic and ecosystem reference conditions that underlie challenges to mitigation and adaptation. These descriptions should be flexible enough to provide a framework for comparison within which regional or local studies of adaptation and vulnerability could build their own narratives. The defining socioeconomic conditions of these scenarios are designated Shared Socioeconomic reference Pathways (SSPs). The SSPs define the state of human and natural societies at a macro scale and have two elements: a narrative storyline and a set of quantified measures that define the high-level state of society as it evolves over the 21st century under the assumption of no significant climate change. This assumption defines the SSPs as a baseline independent of climate change projections. The set of SSPs was chosen to characterize the range of uncertainty in mitigation efforts required to achieve particular radiative forcing pathways, in adaptation efforts that could be undertaken to prepare for and respond to the climate change associated with those pathways, and in residual impacts. This will allow assessment of scenarios along two axes: socioeconomic challenges to mitigation, and socioeconomic challenges to adaptation.

This conceptualization of SSPs allows them to be combined with different degrees of anthropogenic interference with the climate system (measured in terms of radiative forcing as e.g. described in the RCPs). Each combination of an SSP and a radiative forcing level (represented in a matrix, hence matrix approach) defines a family of macro-scale scenarios. A variety of adaptation and mitigation policies are compatible with each family of macro-scale scenarios (i.e. matrix cells).

Shared climate Policy Assumptions (SPAs) define a third axis that includes information on mitigation and adaptation policies, e.g. global and sectoral coverage of greenhouse gas reduction regimes, and the aggressiveness of adaptation in different world regions. This approach facilitates investigation and comparison of different policies, something that was challenging under previous scenario frameworks.

For any combination of SSP, RCP, and SPA, there will be a number of possible climate change projections that are associated with a different model of the physical climate system, adding another dimension to each cell. The resultant scenarios can be used for individual research projects and for integrated assessments of mitigation, adaptation, and residual climate impacts.

The main modes of analysis will be to explore (a) the implications of increasingly stringent mitigation (i.e. lower value RCPs) within any one SSP, e.g. an analysis based on scenarios within one matrix column; (b) the implications of different climate policy assumptions, e.g. increasing adaptation aggressiveness for a given RCP and SSP combination; and (c) the implications of various SSPs within any one category of radiative forcing, e.g. an analysis based on scenarios within one matrix row. There also can be analyses within any one cell (or collection of cells) to examine the implications of using different climate, mitigation, or impact models within an SSP/RCP combination.

The draft framework paper in Annex I was widely circulated to the relevant scientific communities, requesting comments by 16 September 2011. Once these comments are incorporated the paper is to be published in its final form. Based on SSP population and GDP data – to become available for review in spring 2012 – the integrated assessment modelling and impacts communities will start initial work characterizing the SSPs, with the goal of publishing data for illustrative socioeconomic scenarios in time to inform studies to be assessed in the AR5.

Annex I: Paper

A framework for a new generation of socioeconomic scenarios for climate change impact, adaptation, vulnerability, and mitigation research

Coordinating Lead Authors: Nigel Arnell, Tom Kram ***Lead Authors***: Timothy Carter, Kristie Ebi, Jae Edmonds, Stéphane Hallgatte, Elmar Kriegler, Ritu Mathur, Brian O'Neill, Keywan Riahi, Harald Winkler, Detlef van Vuuren, Timm Zwickel

Remarks:

The content of the draft version is preliminary pending comments from the research community. A final version that takes into account comments received will be produced in Fall 2011.

Comments can be submitted through a comment form available on the website of the Boulder workshop on Socio-Economic Pathways at http://www.isp.ucar.edu/socio-economic-pathways. Please use page and line numbers when submitting comments.

The deadline for submission of comments to be taken into account by the author team is **16 September 2011**.

Note: As update to the draft version of this paper published on the website given above, Figure 4.2 has been corrected for the reproduction in this Workshop Report "IPCC Workshop on Socio-Economic Scenarios".

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1. Introduction and Overview

Climate change is projected to impact human and natural systems, with differential consequences across regions, sectors, and time. The magnitude and extent of future impacts will depend on the response of the Earth system to atmospheric composition; the effectiveness of mitigation and adaptation options to avoid, prepare for, and respond to impacts; and on development pathways, including changes in demographics, economies, technologies, and policies. Scenarios can be used to explore and evaluate the extensive uncertainties in each of these. The term *scenario* describes a comprehensive description of the future of the human-climate system, including quantitative and qualitative information. This can be distinguished from the term *pathway* that describes scenario components such as atmospheric concentration or development indicators

Acronyms

CM = Climate Modelling community

CMIP3 = Climate Model Intercomparison Project 3

CMIP5 = Climate Model Intercomparison Project 5

IAM = Integrated Assessment Modelling community

IAV = Impacts, Adaptation, and Vulnerability community[1]

RCP = Representative Concentration Pathways

SPA = Shared climate Policy Assumptions

SSP = Shared Socioeconomic reference Pathways

The roadmap of the new scenario process was laid out in Moss et al. (2008) and summarized in Moss et al. (2010). The process consists of preparatory, parallel, and integration phases that involve the CM, IAM, and IAV communities. The new scenarios will provide quantitative and qualitative narrative descriptions of socioeconomic reference conditions that underlie challenges to mitigation and adaptation, and combine those with projections of future emissions and climate change, and with mitigation and adaptation policies. They will provide a framework for underpinning, creating, and comparing sectoral and regional narratives.

In the *preparatory phase*, IAM teams at IIASA, JGCRI-PNNL, PBL, and NIES produced four **Representative Concentration Pathways (RCPs)** for use in the Climate Model Intercomparison Project 5 (CMIP5). The RCPs were created to jumpstart the analysis process. They were crafted with the climate modelling community as the principal user group (Moss, et al., 2010). There are four RCPs, each defined in terms of its radiative forcing in the year 2100 and direction of change (van Vuuren et al., 2011a).

[1] Past IPCC assessments used the acronym IAV, though usage among researchers in the field varies, with VIA, AVI and AIV often adopted as alternatives. This report retains IAV for consistency with previous reports, but takes no position on the most appropriate formulation, which in any case would not be expected to influence the scenario framework described.

Table 1.1: Representative Concentration Pathways in the Year 2100

	Radiative forcing	CO_2 equivalent concentration	Rate of change in radiative forcing
RCP 8.5	8.5 W/m^2	1350 ppm	Rising
RCP 6.0	6.0 W/m^2	850 ppm	Stabilizing
RCP 4.5	4.5 W/m^2	650 ppm	Stabilizing
RCP 2.6	2.6 W/m^2	450 ppm	Declining

The RCPs provide information that is essential input to climate models, including emissions of greenhouse gases and short-lived species at ½ degree by ½ degree grid scale, and land use and land cover. As stand alone products, the RCPs have limited usefulness to other research communities. First and foremost, they were selected with the sole purpose of providing data to climate models, taking into consideration the limitations in climate models differentiating levels of radiative forcing. They lack associated socioeconomic and ecological data. They were developed using idealized assumptions about policy instruments and the timing of participation by the international community.

Therefore, there is a need to develop socioeconomic and climate impact scenarios that draw on the RCPs and associated climate change projections in the scenario process. Referencing the RCP and climate change projections has two potential benefits; they would facilitate comparison across research results in the CM, IAM, and IAV communities, and facilitate use of new climate modelling results in conjunction with IAV research.

The *parallel phase* has several components. Within CMIP5, CM teams are using the RCPs as an input for model ensemble projections of future climate change. These projections will form the backbone of the IPCC's Working Group I assessment of future climate change in the 5th Assessment Report (AR5). The IAM community has begun exploring new socioeconomic scenarios and producing so-called RCP replications that study the range of socioeconomic scenarios leading to the various RCP radiative forcing levels. In the meantime, IAV analyses based on existing emission scenarios (SRES) and climate projections (CMIP3) continue.

In the *integration phase*, consistent climate and socioeconomic scenarios will inform IAM and IAV studies. For example, IAV researchers can use the new scenarios to project impacts, to explore the extent to which adaptation and mitigation could reduce projected impacts, and to estimate the costs of action and inaction. Also, mitigation researchers can use the global scenarios as "boundary conditions" to assess the cost and effectiveness of local mitigation measures, such as land-use planning in cities or changes in regional energy systems.

These scenarios need to supply quantitative and qualitative narrative descriptions of potential socioeconomic and ecosystem reference conditions that underlie challenges to mitigation and adaptation. And they have to be flexible enough to provide a framework for comparison within which regional or local studies of adaptation and vulnerability could build their own narratives. The defining socioeconomic conditions of these scenarios have been designated **Shared Socioeconomic reference Pathways (SSPs)**.

This document presents a conceptual framework for developing new scenarios using a matrix approach. This approach provides the landscape within which a particular scenario can be located based on the state of human societies (SSPs); the degree of anthropogenic interference with the climate system (measured in terms of radiative forcing as e.g. described in the RCPs); the state of the atmosphere and climate (CMIP5 and other projections); and shared climate policy assumptions. The resultant scenarios can be used for individual research projects and for integrated assessments of mitigation, adaptation, and residual climate impacts.

1.1. Outline of key features of the new scenarios

The scenario matrix approach and its underlying concepts are described in Section 2.

The SSPs define the state of human and natural societies at a macro scale and have two elements: a narrative storyline and a set of quantified measures that define the high-level state of society as it evolves over the 21st century under the assumption of no significant climate feedback on the SSP. This assumption allows the SSP to be formulated independently of a climate change projection. In reality, SSPs may be affected by climate change, which can be taken into account when combining SSPs with climate change projections to generate a socioeconomic-climate reference scenario. In the absence of climate policies, the SSPs may lead to different climate forcing in the reference case and to different changes in climate. See Section 3 for a conceptualization of the SSPs.

Two axes of the scenario matrix are the SSPs and radiative forcing levels (see Figure 1). Each combination of an SSP and a radiative forcing level defines a family of macro-scale scenarios. Because the RCP level provides only a rudimentary specification of mitigation policy characteristics, and very little information on adaptation policies, a third axis embeds RCPs in **Shared climate Policy Assumptions (SPAs)** that include additional information on mitigation and adaptation policies, e.g. global and sectoral coverage of greenhouse gas reduction regimes, and the aggressiveness of adaptation in different world regions. Obviously, there can be more than one SPA for a given radiative forcing level. For any combination of SSP, RCP, and SPA, there will be a number of possible climate change projections that are associated with a different model of the physical climate system, adding another dimension to each cell. See Section 4 for a discussion of SPAs.

Not every cell of the scenario matrix need be populated. For example, an SSP that is defined such that population growth decreases rapidly and renewable energy costs are quickly reduced may be inconsistent with radiative forcing reaching 8.5 Wm^{-2} in 2100. However, scenarios associated with lower radiative forcing can be populated assuming appropriate levels of mitigation. The degree of global climate mitigation stringency is inversely related to the level of radiative forcing in the year 2100: the wider the gap between baseline forcing and an RCP level, the more effort will be required to close it. Thus, by definition, smaller radiative forcing in 2100 implies greater mitigation stringency.

Main modes of analysis will be to explore (a) the implications of increasingly stringent mitigation within any one SSP, e.g. an analysis based on scenarios within one column; (b) the implications of different climate policy assumptions, e.g. increasing adaptation aggressiveness for a given RCP and SSP combination; and (c) the implications of various SSPs within any one category of radiative forcing, e.g. an analysis based on scenarios within one row. There also can be analyses within any one cell (or collection of cells) to examine the implications of using different climate, mitigation, or impact models within an SSP/RCP combination.

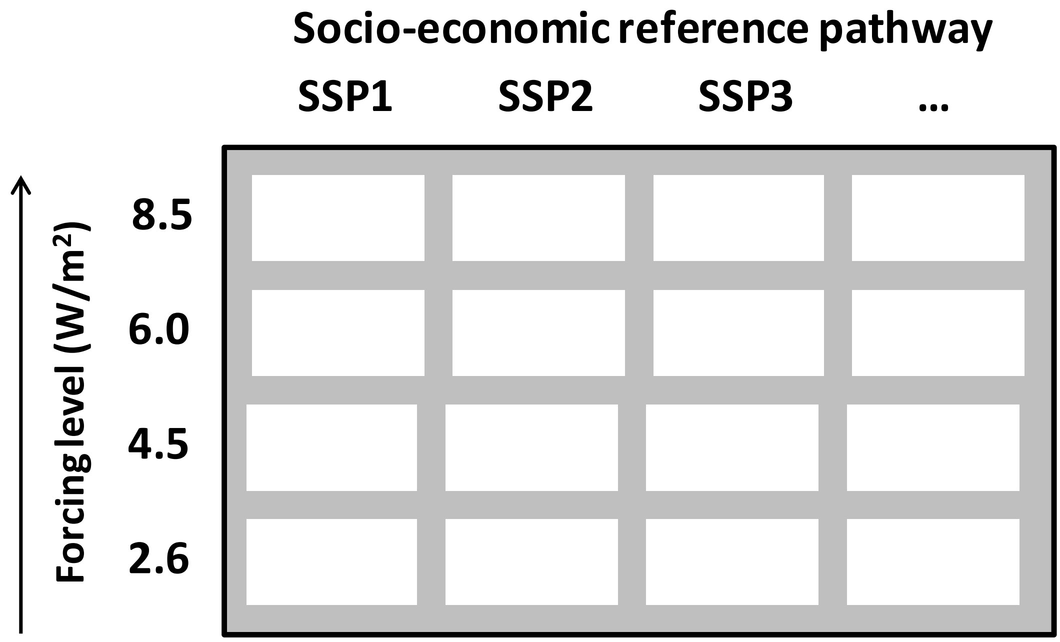


Figure 1.1: The scenario matrix architecture: confronting different future levels of climate forcing with different socio-economic reference assumptions described by SSPs. See Section 2 for details.

1.2. Scenarios in previous assessments

Global change scenarios widely used include those of the Special Report on Emissions Scenarios (SRES), the scenarios developed for the Millennium Ecosystem Assessment, and the GEO-4 scenarios.

The SRES set of scenarios was developed to represent the range of driving forces and emissions in the scenario literature, to reflect current understanding about underlying uncertainties (Nakicenovic, 2000). The scenarios were based on an extensive assessment of driving forces and emissions in the scenario literature, alternative modelling approaches, and a process that solicited wide participation and feedback. Four narrative storylines were developed to consistently describe the relationships between emission driving forces and their evolution, with each storyline representing different demographic, social, economic, technological, and environmental development pathways. The scenarios cover a wide range of the main demographic, economic, and technological driving forces of GHG and sulfur emissions. For each storyline, several different scenarios were developed using different modelling approaches to examine the range of outcomes arising from models that use similar assumptions about driving forces. Contrary to the new scenarios described here, the SRES scenarios assumed no specifically targeted climate mitigation and adaptation policies and measures. In subsequent studies and assessments, such extensions to the original SRES set were explored extensively.

The Millennium Ecosystem Assessment (MEA) was a large assessment of the current status, present trends, and longer-term challenges to the world's ecosystems, including climate change and other sources of stress. The MEA sought to assess changes in ecosystems in terms of the services they provide to people and the effects of ecosystem change on human well-being; and to identify and assess methods to mitigate and respond to ecosystem change. Scenarios to 2050, with more limited projections to 2100, were developed in an iterative process, including consultations with potential scenario users and experts (Carpenter, 2005). Two basic dimensions of uncertainty in long-term ecosystem stresses were identified: globalization (continuation and acceleration of present global integration trends, versus reversal of these trends to increasing separation and isolation of nations and regions) and whether responses to increasing ecosystem stresses are predominantly reactive – waiting until evidence of deterioration and loss of services is clear – or predominantly proactive, taking protective measures in advance of their clear need. The extreme values of each of these dimensions yielded four scenarios, summarized in table 1.2.

Table 1.2: The Millennium Ecosystem Assessment scenarios.

ECOSYSTEM MANAGEMENT	WORLD DEVELOPMENT	
	Global	Regional
Reactive	Global Orchestration	Order from Strength
Proactive	TechnoGarden	Adapting Mosaic

The GEO-4 conceptual framework is based on the drivers-pressures-state-impacts-responses (DPSIR) concept that reflects the key components of the complex chain of cause-and- effect relationships that characterize the interactions between society and environment at all spatial scales, from global to local (Agard et al., 2007). Environmental changes are induced by drivers and caused by pressures, and also affect each other. Responses include measures by society for mitigating and adapting to environmental changes. Through the GEO-4 scenario exercise, stakeholders explored the interplay between some of the environmental issues in atmosphere, land, water and biodiversity. The scenarios were based on assumptions related to institutional and socio-political effectiveness, demographics, economic demand, trade and markets, scientific and technological innovation, value-systems, and social and individual choices, and highlighted areas of uncertainty in the coming decades. The main scenarios are:

- Markets First: the private sector, with active government support, pursues maximum economic growth as the best path to improve the environment and human well-being for all.
- Policy First: the government sector, with active private- and civic-sector support, implements strong policies intended to improve the environment and human well- being, while still emphasizing economic development.
- Security First: the government sector and the private sector vie for control in efforts to improve, or at least maintain, human well-being for mainly the rich and powerful in society.
- Sustainability First: the civic, government and private sectors work collaboratively to improve the environment and human well-being for all, with a strong emphasis on equity.

2. The scenario framework: main concepts

2.1 Criteria for a new scenario framework

The CM, IAM, and IAV communities use scenarios in different ways and for different purposes. Therefore, their requirements for scenarios differ, including relative emphases on scenario elements and approaches. At the same time, the communities use each other's results and insights, and they collaborate in research and scientific assessment activities, such as the Intergovernmental Panel on Climate Change (IPCC), with its working groups corresponding to the three major research communities. Policy relevant questions for research and assessment include the interactions among and trade-offs between adaptation and mitigation responses, and options to deal more effectively with the challenge of understanding multiple stresses. There is a clear benefit from scientific and policy perspectives if a subset of scenarios provides a connecting and integrative thread across the three communities. There also is clear benefit to being able to synthesize across studies of climate modelling, impacts, adaptation and mitigation options, and co-benefits to, for example, estimate costs of action and inaction under different scenarios. The scenarios discussed in this paper are designed to serve these purposes.

Projections of future impacts, adaptation, and vulnerability, need qualitative and quantitative information on climate (change) and the status of the exposed system (to assess its sensitivity and adaptive capacity, which strongly depend on socioeconomic conditions). Scenarios in IAM models mostly concentrate on mitigation, primarily related to the technological implications of different stabilization targets and their associated costs. Taken together, these suggest that key factors in the interaction between the different disciplines include:

- The level of climate change and associated impacts;
- Trends in human development in relation to drivers of climate change, the ability to mitigate greenhouse gas emissions, and the ability to adapt to climate change.

A useful scenario framework would predominantly include these two elements. Other design criteria can be derived from the intended purposes of the scenarios (Van Vuuren et al., 2011b; Kriegler et al., 2011):

1. **Limited number**: The set of scenarios should be as small as possible, consistent with other scenario design criteria.

2. **Comprehensive.** The framework needs to cover sufficiently different future development to represent a plausible range of assumptions and thus represent relevant uncertainties.

3. **Comparability**. The scenario set should make it possible for some research knowledge generated in one community to be compared with information generated in another.

4. **Relate adaptation, mitigation, and climate impacts.** The scenarios should provide a means of synthesizing information from the three climate research communities in a way that highlights the similarities and differences among alternative potential climate futures, and that allows estimation of associated costs.

5. **Multiscale**. The storylines should provide enough explicit information on the aggregated scale to be clearly distinguishable also at finer scales. Similarly, storylines and scenarios should embrace near-term and long-term future conditions; the former providing linkages to ongoing trends and planning horizons, and the latter accommodating plausible large-scale divergences in key driving factors.

6. **Structured but flexible**. The scenario set should provide enough structure to facilitate consistency, and offer context and calibration points for IAV and mitigation analyses, but also offer flexibility for defining relevant details.

2.2 The scenario matrix approach

2.2.1. Need for new socioeconomic scenarios

The emission scenarios underlying the RCPs provide a consistent combination of socioeconomic parameters, such as population, income, energy use, land use, emissions and climate. However, as shown by Van Vuuren et al. (2011b), as a set these scenarios do not match another important criterion, e.g. a wide coverage of the literature. In that context, it should be noted that the emission scenarios were selected from the literature on the basis of their joint coverage of a wide radiative forcing range. The socioeconomic parameters are based on specific assumptions of each individual team and for most RCPs represent medium assumptions. There is no logical story behind the assumptions of the RCP set as a whole.

This raises the question as to whether it is possible to combine different socioeconomic scenarios and forcing levels. The SRES-report (Nakicenovic et al., 2000) found that for each forcing level, multiple emission pathways can be identified. More recently, Van Vuuren et al. (2011b) confirmed that very little correlation exists between the population and economic assumptions of climate policy scenarios and the forcing levels. In other words, for a given set of such socioeconomic boundary conditions, it is possible to project a very wide but credible range of future emissions, radiative forcing, and climate. Similarly, a given emissions pathway may be reached under a wide variety of socioeconomic boundary conditions.

2.2.2. The scenario matrix approach as an overall organizing principle

The scenario matrix approach is based on two crucial elements: radiative forcing level (as an organizing variable for climate change); and the socioeconomic assumptions underlying the scenarios.

Assumptions about socioeconomic development are important 'drivers' of scenarios, including the scenario narrative, and qualitative and quantitative assumptions about broad development patterns for major world regions. A scenario combines these assumptions with a quantitative dynamic analysis in a model. Therefore, scenarios include assumptions and derived quantifications of additional socioeconomic indicators relating to energy or land use (or if additional models are used, parameters such as health). Model assumptions and the model output parameters can be relevant for IAM and IAV analysis. To group scenarios, a minimum set of assumptions should (to some degree) be shared among all scenarios in a group. This minimum set ensures some amount of consistency. The elements of the socioeconomic reference scenario that are shared among all possible manifestations in a column of the scenario matrix form a **Shared Socioeconomic reference Pathway** or **SSP**. For the purpose of the SSP within the scenario matrix, we explicitly assume that in their original form they do not include climate policy and that these assumptions are not influenced by climate change. As such they form a reference that defines the columns of the matrix in Figure 1.

The primary objective of the SSPs is to provide sufficient information and context for defining development pathways that can be used as a starting point for IAM and IAV analyses, at the same time differing significantly in the challenges to mitigation and adaptation. The SSPs thus comprise a set of narratives and quantitative information on the drivers of how the future might unfold. The quantitative information from that scenario will include an internally consistent set of input assumptions that can be used directly by different types of models for the development of reference scenarios. The SSPs are discussed further in Section 3.

In Figure 2.1, the SSPs form the horizontal axis in the scenario matrix and the RCPs form the vertical axis (Moss et al., 2010). This is a natural choice because radiative forcing constitutes the most useful interface between the IAM (translating emissions drivers to forcing) and CM communities (translating forcing to climate change). The CM community is conducting multiple modelling experiments to investigate the climate response to the RCPs. It should be noted that, in fact, the radiative forcing axis is continuous, which means that scenarios (in particular those without explicit climate targets) could end up at places along this axis that do not correspond to a specific RCP. How the climate projections from the RCPs can be used with these scenarios needs further elaboration.

One column of the matrix thus contains scenarios constructed from the family of socioeconomic reference pathways and the radiative forcing levels of the RCPs. The elements of an SSP can change when moving from a reference to a policy scenario as a result of climate change and climate policy (adaptation or mitigation). This does not limit the ability to separate the RCP and SSP dimensions because all scenarios within a column refer to a single reference SSP.

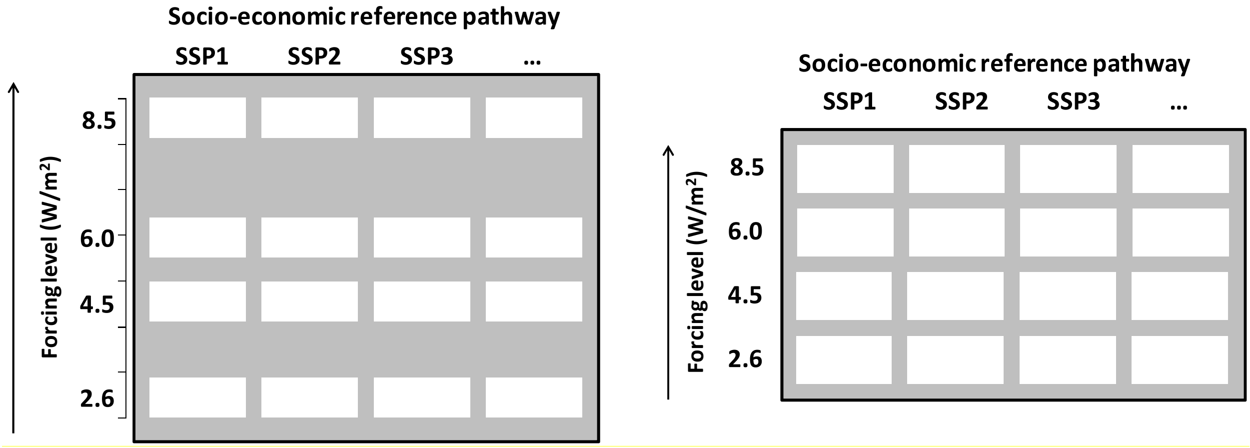


Figure 2.1: The scenario matrix architecture: confronting different future levels of climate forcing with different socioeconomic reference assumptions described by SSPs. The number of SSPs has been chosen for illustrative purposes. The forcing levels are chosen to correspond to the forcing level reached by the RCPs. The left-hand panel shows the matrix with equidistant vertical axis, illustrating the relative position of the RCPs on the forcing scale. The right-hand panel shows a simplified version of the matrix that is used throughout this report.

2.2.3 Common policy assumptions

A series of additional assumptions are needed about adaptation and/or mitigation policies to derive a policy scenario consistent with a given combination of an RCP and an SSP. Examples are cooperative vs. non-cooperative action and sectoral flexibility in using the least cost mitigation options, and adaptation preparedness in different world regions; the effectiveness and costs of mitigation and adaptation depend on these assumptions. Analogous to the socioeconomic reference assumptions, another dimension of the matrix architecture is a set of **Shared climate Policy Assumptions (SPA)** that characterize the types of climate policies. In practice, each research team will make its own assumptions about climate policies to reach a given RCP. The SPAs will be an attempt to categorize the key elements of those assumptions beyond the RCP level. In a scenario with climate policy (in particular mitigation), some scenario elements (like energy use and land use, or GDP size and sectoral composition) are bound to differ from the reference scenario; these may include elements of the SSP. In the mitigation example, the new model output GDP replaces the SSP assumption.

Climate policy scenarios are derived by combining an SSP and SPA (e.g. a set of climate policies designed to achieve a given RCP level), and, possibly, climate change projections. Because GDP and other variables would be affected by the climate policies and climate change impacts, model outputs would replace reference SSP assumptions when and where they were significantly different. Climate policy scenarios generally include assumptions about adaptation, framed by the SSP narrative and the assumed SPA characteristics. The analysis of mitigation policies may be conducted without explicitly taking climate change projections into account.

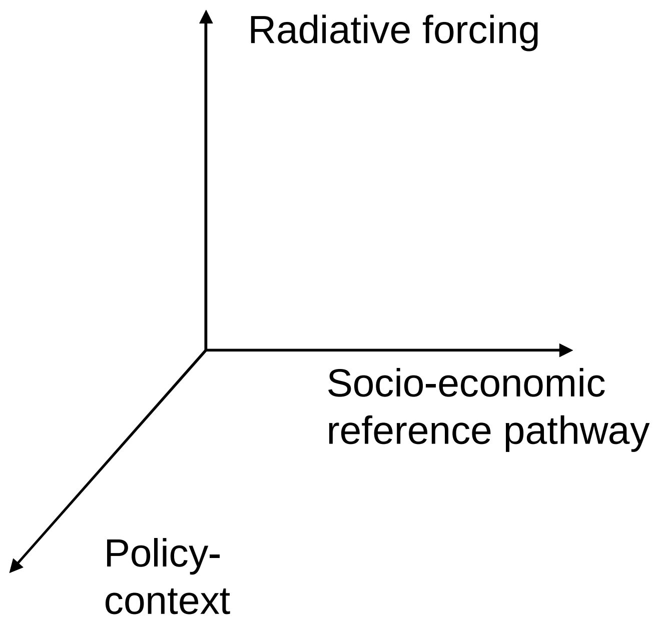


Figure 2.2: The policy context may still vary within a SSP. Therefore, the policy context can be defined as an additional axis to explore in scenario analysis. Note it is not implied that the forcing level and the policy context, nor the policy context and the SSP, are uncorrelated.

2.3.4 The climate dimension

The vertical axis in the scenario framework is defined in terms of RCPs, i.e. the level of radiative forcing. As explained above, the choice is made for practical reasons (RCPs form the connecting element between IAM and CM models; radiative forcing targets are commonly used across IAM model analysis). It should be noted that climate impacts may differ strongly even within a certain radiative forcing level. Global mean temperature change is not directly determined by forcing level alone; factors such as climate sensitivity and the pattern of climate change play a key role. Climate impacts are usually a result of more than temperature change alone. For example, precipitation, radiation, wind, and humidity can have important effects on society and natural systems. Impacts also depend critically on the timing, pattern, frequency, duration, and intensity of weather events, especially extreme events. As shown by several studies, including Arnell et al. (2011), for instance, the same level of climate change defined in terms of change in global mean temperature may result in very different changes in the risk of water scarcity as a function of the direction, magnitude, and pattern of changes in precipitation and their interplay with population density. Thus, projections obtained from a single climate model for a given RCP level might indicate changes in climate that contrast greatly from projections from another climate model for the same forcing. Therefore, there are additional uncertainties to account for in deploying this scenario framework. For near-term scenarios, in which pathways of concentrations vary little across different RCPs, it is the climate model uncertainty (especially the representation of natural variability of climate) that dominates projections of future climate. The importance for climate of the concentration pathway on which the world has embarked, described by the RCPs, only becomes apparent when the RCPs diverge in the second half of the 21st century.

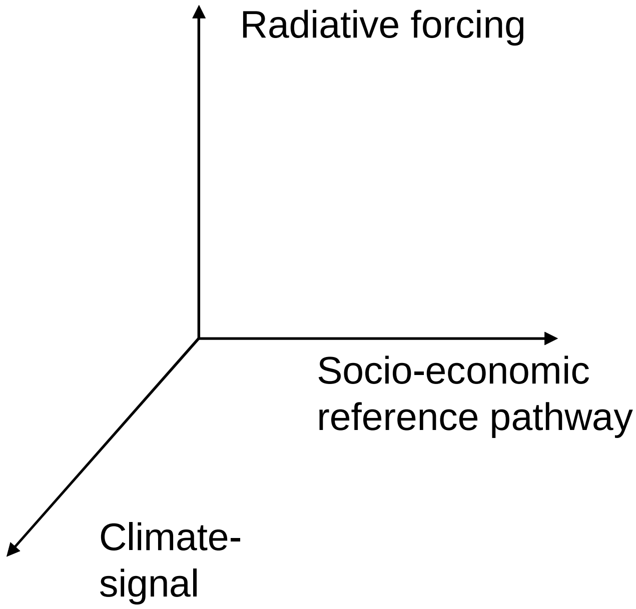


Figure 2.3: The uncertainty in the climate signal as a function of the forcing level plays out as an additional axis to explore in scenario analysis. Note it is not implied that the climate signal and forcing level are uncorrelated.

2.3 The scenario matrix approach in relation to IAM and IAV analysis

An important feature of the scenario matrix is that its individual cells describe the interplay between adaptation and mitigation and the resulting residual climate impacts. Using the matrix as an organizing principle allows research to explore a wide range of relevant combinations between contributing factors.

The scenario matrix architecture can be used in different ways for scientific and policy analyses. For instance, impact, adaptation, or vulnerability analysts could compare consequences under the same climate scenario (RCP driven) across all socioeconomic scenarios (along a row: "what is the effect of future socioeconomic conditions on the impacts of a given climate change"). Or, they could compare consequences under a given socioeconomic scenario with different degrees of climate change (down a column: "how do the impacts of climate change in a given future world vary with the magnitude of change"). An assessment of the effects of mitigation and adaptation compares consequences down a column; an assessment of the effect of future socioeconomic conditions on the effectiveness and costs of a suite of mitigation and adaptation measures would compare the differences between columns. A comprehensive analysis covers all cells, calculating for example adaptation costs, mitigation costs, and residual damages in each cell. This is explored in a little more detail below.

How do the impacts of climate change and climate policy in a given future vary with the magnitude of change?

Scenarios without climate policy (reference scenarios) may end up at different places along the radiative forcing axis. Further, as illustrated in Figure 2.4, models can interpret an SSP in different ways. In this example, at the same time, on average SSP3 may have higher radiative forcing levels than SSP1.

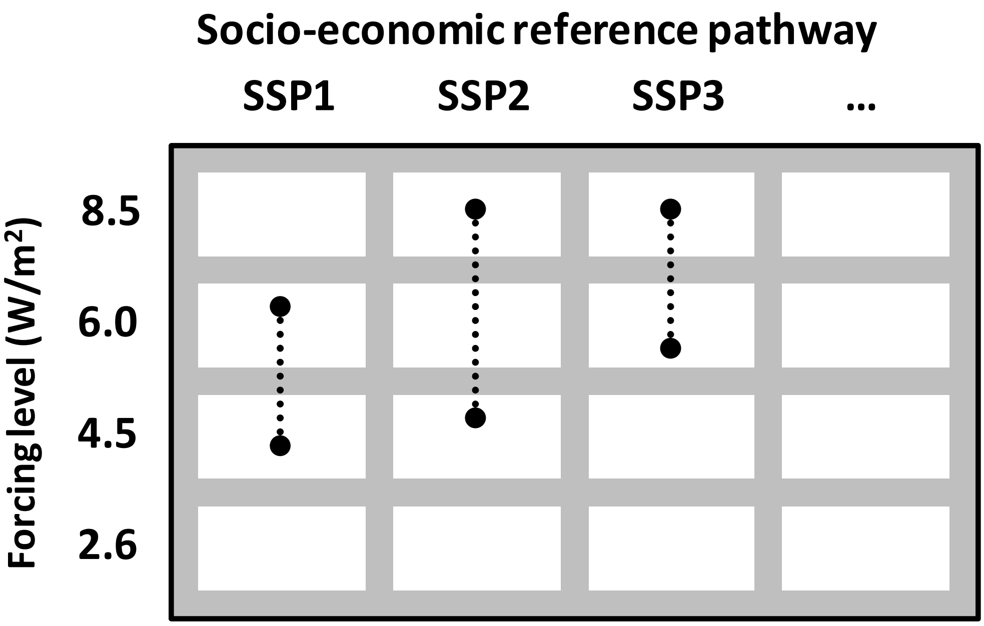


Figure 2.4: The scenario matrix architecture and possible reference scenario forcing (the lines indicate the uncertainty due to the different possible interpretations of the SSPs by different model teams).

Mitigation policy can move the climate forcing from one cell to another within a given column, Figure 2.5. The mix of policies that are necessary vary between columns and between cells in a column. The framework therefore allows the coherent analysis of the effects of climate policy.

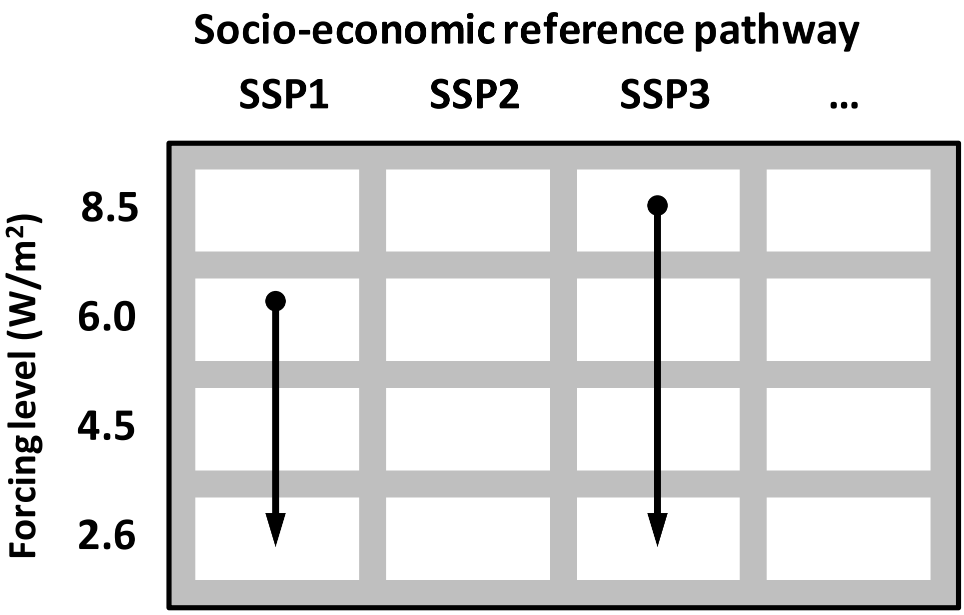


Figure 2.5: The scenario matrix architecture can be used to explore the costs and benefits of mitigation action for a certain socioeconomic reference assumption described by an SSP.

It is also possible to analyze the costs of mitigation and/or adaptation along the RCP axis, Figure 2.6. For example, one could compare a consistent set of reference and climate policy scenarios in terms of abatement costs, changes in total and sectoral GDP, trade, emissions of different gases, etc. to assess the cost of mitigation policy. The scenario matrix architecture facilitates the consistent evaluation of the costs of mitigation, adaptation, and residual climate damages. The results would depend on different choices for the SPAs.

Conducting this experiment using several reference scenarios or different models provides a sensitivity analysis of how robust the policy is to different reference world evolutions.

What is the effect of future socioeconomic conditions on the impacts of a certain degree of climate change?

The presence of several different SSPs allows one to explore the consequences of different SSPs on climate impacts, but also on the effectiveness of climate policy.

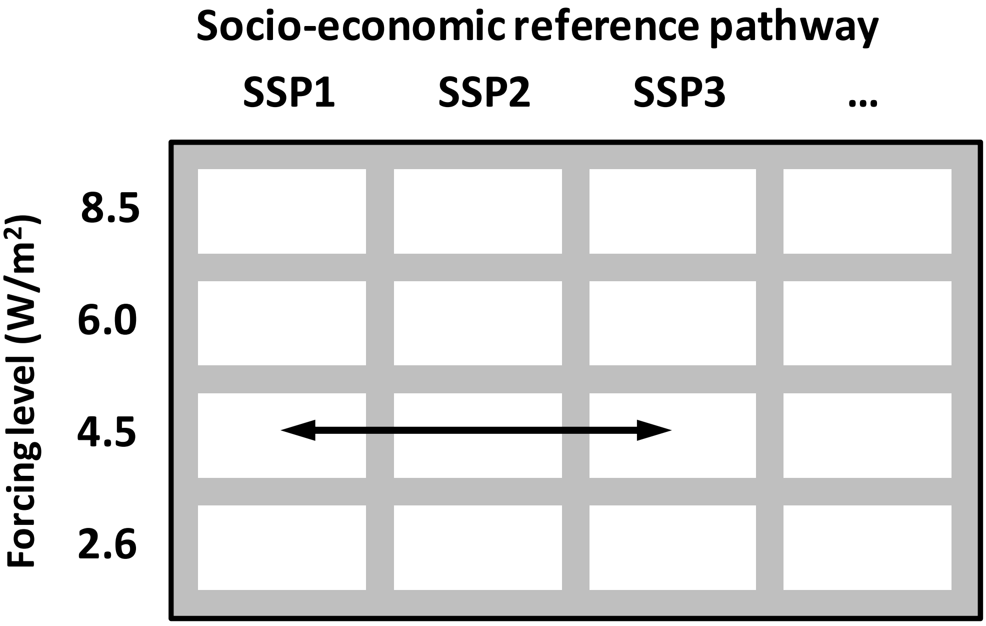


Figure 2.6: Comparing results along one row of the scenario matrix show how mitigation, adaption, and remaining climate impacts play out under different socioeconomic futures.

Figure 2.7 summarizes the two dimensions of climate change and climate policy analysis using the scenario matrix approach. The range of radiative forcings in the reference case will vary with SSP, and there may be SSPs for which very high forcings such as RCP8.5 will not be obtained even in the reference case. Similarly, the challenges to mitigation and adaptation will vary with SSP, so that different levels of mitigation costs, adaptation effectiveness, and residual climate damages will be obtained for a given RCP level in different SSPs. These effects can be explored by a comparison of studies bridging different cells across the columns and rows of the matrix. A fully integrated analysis of impacts, adaptation, vulnerability, and mitigation would include feedbacks to the initial (exogenous) boundary conditions presented by the SSP. For example, it may be the case that impacts, adaptation, and mitigation reduce (or increase) GDP or alter population movements, initially assumed exogenous for all cells in a column. The "output" GDP or population distribution would then be different for each cell in a column (because the climate change is different and climate policies have been introduced).

It should be noted that it seems preferable to include 3.7 W/m^2 in a set of preferred scenarios because this forcing level is an important part of ongoing policy-making activities. Analyses of the mitigation and adaptation implication of this forcing level could be informative for policy-makers.

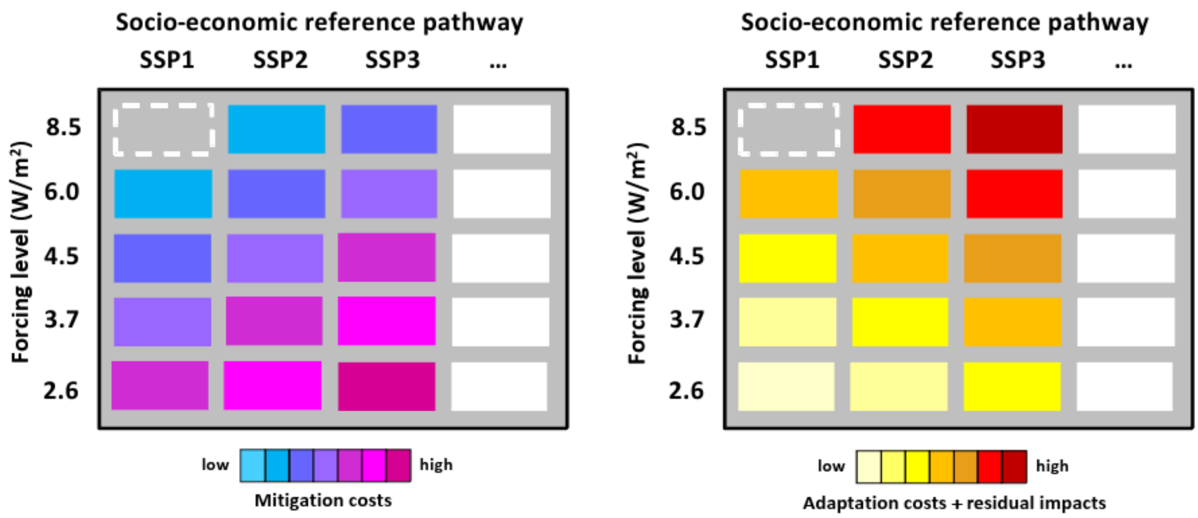


Figure 2.7: Illustrative indications of how climate policy costs and residual impacts may vary across the cells of the matrix. The empty box (dashed lines) illustrates that not all combinations of forcing levels and SSPs may be consistent. The 3.7 W/m2 level was added to illustrate that this is an important forcing level for policy-makers.

2.4 Different ways to use the scenario matrix architecture

There are different ways in which the scenario matrix architecture can be used for further scenario analysis:

- The scenario matrix as a heuristic tool: the matrix may help to classify existing scenarios and new scenarios developed by different modelling groups.
- The scenario matrix as basis for new scenario development, including the use of markers: scenarios may also be developed explicitly based on the matrix using available storylines and marker scenarios.

2.4.1 The matrix as heuristic tool

One important use of the matrix structure is as a heuristic tool. The matrix offers an opportunity to classify typical examples of combinations of factors that are crucial for adaptation and mitigation from the literature. By locating published studies in different cells of the matrix, these studies can more readily be compared and evaluated, as illustrated in the following examples.

Example 1: Different studies have estimated the costs of mitigation policy using baselines where the capacity of mitigation varied. For instance, some scenarios included high technology development and global cooperation, while other scenarios assumed technology development was low and global cooperation was lacking. Classifying scenarios from the literature within the matrix would allow researchers to account for these differences and only compare scenarios with similar assumptions. Remaining uncertainties would obviously still result in a range of possible outcomes within a cell.

Example 2: Various studies estimated the impacts of and adaptation costs for flooding. These studies used different assumptions about adaptive capacity and levels of climate change. Again, the matrix can help to classify studies in a common way and provide a framework of communication across various communities.

To achieve this purpose, criteria need to be established whether a scenario aligns with SSP1, SSP2, or SSPn, and/or with different forcing levels. Categories of scenarios are available in the literature (Raskin et al., 2005; Van Vuuren et al., 2011b; Rounsevell and Metzger, 2010). Box 2.1 discusses an attempt by van Vuuren et al. (2011b) to identify scenario archetypes or families in the literature across different assessments.

Box 2.1: Classification of existing scenarios from GEAs

Over the last 10 years, a large number of global environmental assessment studies have been published that include scenario projections. Comparison of these studies shows there is a limited set of scenario families based on the same explorative storylines that form the basis of many scenarios used in different environmental assessments. Mapping these scenarios within these families allow a more easy comparison across different assessments. The fact that many assessments can be positioned within these scenario families gives some confidence in their relevance. At the same time, it is also noticeable that several recent assessments focused on simple policy-scenarios as variants to a single baseline.

The six scenario families that can be observed are: 1) economic-technological optimism/conventional markets scenarios; 2) reformed market scenarios; 3) global sustainability scenarios; 4) regional competition/regional markets scenarios; 5) regional sustainable development scenarios; and 6) business-as-usual/intermediate scenarios. Table 3 summarizes the main characteristics of these scenario families.

Table 3: Key assumptions in different "scenario families"

	Economic optimism	**Reformed markets**	**Global SD**	**Regional competition**	**Regional SD**	**Business as Usual**
Economic development	Very rapid	Rapid	Ranging from slow to rapid	Slow	Ranging from mid to rapid medium	Medium (globalization) medium
Population growth	Low	Low	Low	High	Medium	Medium
Technology development	Rapid	Rapid	Ranging from mid to rapid	Slow	Ranging from slow to rapid	Medium
Main objectives	Economic growth	Various goals	Global sustainability	Security	Local sustainability	Not defined
Environmental	Reactive	Both reactive and proactive	Proactive	Reactive	Proactive	Both reactive and proactive
Trade	Globalization	Globalization	Globalization	Trade barriers	Trade barriers	Weak globalization
Policies and institutions	Policies crate open markets	Policies reduce market failures	Strong global governance	Strong national governments	Local steering; local actors	mixed

Note: This table summarizes key assumptions in very general terms. Where differences within a set of scenario families exist, broad ranges are indicated.

2.4.2. Use of marker scenarios

The scenario framework can also be explicitly used to develop new scenarios. For this purpose, one would need to define elements for each SSP/radiative forcing combination that would guide new development. There is a trade-off between harmonization and providing flexibility. Any new scenario framework should provide flexibility and not over-specify scenarios. Reasons for this include the need to communicate existing uncertainties, to allow for different approaches, to avoid constraints on research directions, and to provide an opportunity for a wide research community to participate in scenario analysis. At the same time, however, the scenarios also have a function to organize information (acts as a thread to the communities), which benefits from some form of standardization.

In this context, we propose the following steps.

- The basic SSPs include a minimum set of qualitative and semi-quantitative descriptions (see Section 3) allowing for a great flexibility in interpretation of the underlying narratives, including a preferred range for basic quantitative indicators and key model input assumptions such as population and income.

- The scientific community should be encouraged to submit scenarios to populate the different cells within the framework based on simple criteria that define the columns/cells.

- Define specific "marker" scenarios that are considered illustrative of the type of scenarios within the framework (similar to what was done for SRES). These markers or illustrative scenarios are not the only possible quantification of a SSP (or SPA), but will preferably be used in most analyses as a basis for comparison, in addition to using other scenarios from a specific element in the framework. In the definition of the markers, it can be decided the degree to which parameters are specified – and how much is left as choice for individual analysts.

2.4.3 Uncertainty in climate policy and climate impact

A similar discussion exists regarding the specification of the climate projections along the RCP axis. At the very least, there is a need to indicate clearly how future climate and its uncertainties have been characterized using different climate models, as the use of different climate models may lead to very different results. The methods by which climate uncertainties associated with similar levels of radiative forcing are to be addressed by IAV and other analysts remain to be determined, and it is important that further guidance be provided on how to handle these important choices (e.g. by clearly identifying the characteristics of different CM model runs).

3. Defining the Shared Socioeconomic Pathways (SSPs)

3.1 Introduction

As discussed in Section 2, the intent of this process is the development of scenarios based on combinations of climate model projections, socioeconomic conditions, and assumptions about climate policies (including a no policy reference). Narratives and qualitative and quantitative assumptions about broad development patterns for major world regions, relevant to impacts, adaptation, and mitigation, define the SSPs. These assumptions include common inputs required by integrated assessment and impact models, but not typical model outputs such as greenhouse gas emissions. It is desirable to develop a set of scenarios that present a broad range of possible development pathways; with reference scenarios based on SSPs and assumptions of no (new) climate policy, and policy scenarios based on SSPs combined with assumptions about climate policies for reaching a given RCP level.

This section discusses the framework for defining the content of SSPs. We first discuss the logic used to define the space of possible futures that the set of SSPs is intended to span, and the relation of this space to the scenario matrix architecture. We then discuss the dimensions of socioeconomic systems that might be used to specify particular SSPs, including demographic, economic, institutional, and other dimensions. We distinguish two variants of SSPs – basic vs. extended – that provide different levels of detail about future development pathways. Finally, we provide an illustration of the SSP concept by revisiting the choices made in the Special Report on Emissions Scenarios (SRES), and showing how they relate to the concepts contained in this framework paper.

3.2 The logic behind the definition of the SSPs

As discussed in Section 2, one of the key aims of the scenario matrix architecture is to facilitate research and assessment that can characterize the range of uncertainty in mitigation efforts required to achieve particular radiative forcing pathways, in adaptation efforts that could be undertaken to prepare for and respond to the climate change associated with those pathways, and in residual impacts. These outcomes will depend on assumptions regarding future socioeconomic conditions. To encompass a wide range of possible development pathways, the SSPs are defined along two axes: socioeconomic challenges to mitigation, and socioeconomic challenges to adaptation (Figure 3.1).

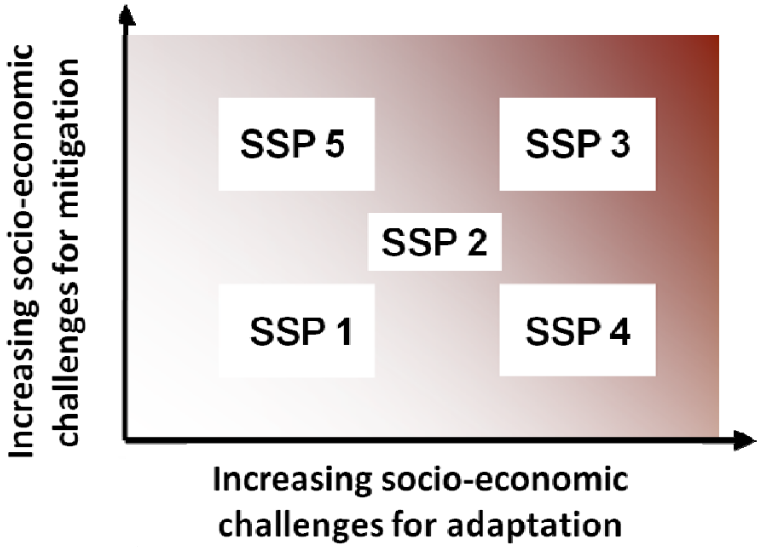


Figure 3.1: The scenario space to be spanned by SSPs.

Challenges to mitigation for the purpose of defining SSPs do not include the mitigation target itself, which is implied by the SPAs and the RCP forcing level. Rather, these challenges are defined by factors that would make the mitigation task easier or harder *for any given target*. For example, in the matrix architecture, a target would be defined by the radiative forcing pathway defining the rows of the matrix, while the challenges to mitigation would be defined by the nature of the SSPs in the columns of the matrix.

Socioeconomic challenges to mitigation are defined as consisting of: (1) factors that tend to lead to high *reference emissions* in the absence of climate policy because, all else equal, higher reference emissions makes that mitigation task larger; and (2) factors that would tend to reduce the inherent *mitigative capacity* of a society. High reference emissions could be generated in a large number of ways, with possible contributions from high population growth rates, rapid economic growth, energy intensive economic systems, carbon intensive energy supplies, etc. More fundamental processes could drive each of these factors, such as technological and social changes that include (autonomous) energy efficiency improvements, fossil fuel availability, and dietary choices. Not all factors need operate in the same direction in order to produce high (or low) reference emissions. For example, neither high population growth nor high economic growth on its own is necessarily associated with high reference emissions in existing scenarios (van Vuuren et al., 2011b). However, combinations of these drivers acting together can be expected to lead to high emissions in a reference case. An SSP would include assumptions about particular combinations of emissions drivers. There is a tension between having an outcome (such as high or low reference emissions) when designing an SSP in order to occupy a particular part of the scenario space depicted in Figure 3.1, and avoiding the specification of outcomes. Model outcomes such as emissions should be part of scenarios based on SSPs, rather than part of SSPs themselves, which emphasize development pathways and drivers. It is likely that some iteration between the design of SSPs, and the development of scenarios based on them, will be necessary before the set of SSPs and reference scenarios is developed that most effectively spans the space of future outcomes.

Factors that tend to influence the mitigative capacity of a society include the range of viable technological options, national and international institutions for policy making, the availability of financial resources necessary to support mitigation activities, stocks of human and social capital, and political will (Yohe, 2001; Winkler et al., 2007; Klein et al., 2007). High (or low) mitigative capacity can result from one or more of these factors, and need not involve all factors influencing capacity in the same direction. It also may be the case that key determinants of mitigative capacity, including the capacity for technological change in energy systems, overlap significantly with determinants of reference emissions, making these two components of challenges to mitigation closely related. Because internal consistency is important, it will limit the freedom to 'pick and choose' from ranges for each individual factor enhancing or limiting mitigative capacity.

Socioeconomic challenges to adaptation are defined as societal conditions that, by making adaptation more difficult, increase the risks associated with any given climate change scenario. Climate change risks arise from the combination of climate hazards, who or what is exposed to those hazards, and the associated vulnerability, whether it is geographic, socioeconomic, cultural, etc.[2] Within the scenario matrix architecture, the component of climate change risk due to climate hazards is reflected in climate model projections based on the RCPs, and therefore should not be contained in the SSPs. The remaining components of risk are inherent to human-environment systems potentially exposed to those hazards, and therefore are appropriately included in the SSPs. Adaptation effectiveness, in the absence of specific adaptation policies, is a function of existing autonomous adaptation or that could be expected to develop without external intervention, which in turn is affected by the severity of the climate change, sensitivity to its potential impacts, and the adaptive capacity to deploy coping measures. The socioeconomic driving factors that influence future adaptation effectiveness are described in each SSP.

Exposure is the presence of people, livelihoods, infrastructure, ecosystem services and resources, and economic, social, and cultural assets in places that could be adversely affected by a climate hazard. For example, a population that is concentrated near a coastline has potentially high expo sure to the impacts of sea level rise, while one that is heavily concentrated in urban areas has potentially high exposure to urban heat waves. Sensitivity indicates the responsiveness of socioeconomic systems to a given amount of climate change; it can be described by an exposure-response relationship (Fuessel and Klein, 2006). If coastal populations live in poorly constructed housing, for example, they would be more sensitive to the increased storm surges associated with sea level rise compared to a population living in better-constructed buildings. Likewise, an urban population that has higher proportions of elderly residents, or that lacks widespread air conditioning, would be more sensitive to urban heat waves.

Adaptive capacity indicates the ability of a society to adjust to climate change in order ameliorate its consequences or to take advantage of opportunities. Factors that influence this capacity include the availability

[2] The definitions of hazard are similar across research communities, as are definitions of who or what is at risk (including physical, socioeconomic, and ecological components). However, vulnerability is defined differently. The AR4 defined vulnerability as consisting of exposure to climate change hazards, sensitivity of socioeconomic or ecological systems to them, and the adaptive capacity of these systems (AR4; Fuessel & Klein, 2006; Fuessel, 2007). This definition describes a future state that takes into account efforts to reduce sensitivity (e.g. coastal vulnerability to sea level rise at some future date would take into consideration the extent to which coastal defenses would be augmented). A complicating factor for the purposes of defining socioeconomic challenges to adaptation is that this definition includes the nature of the climate hazard itself, which should be excluded from SSPs. Thus, using the AR4 definition, challenges to adaptation are socioeconomic elements of exposure, sensitivity, and adaptive capacity. Many impact sectors and the disaster risk community view vulnerability differently, focusing on describing current and future internal characteristics of socioeconomic or ecological systems that increase (decrease) the susceptibility to harm. Vulnerability, then, is a description of the socio-ecological elements of exposure, and the factors leading to increased/decreased susceptibility to that exposure, including past adaptation efforts. In this perspective, adaptive capacity describes the socio-ecological potential for decreasing future vulnerability, assuming that potential is deployed. These different perspectives lead to similar determinants of the risks of the possible magnitude and extent of future impacts to a given degree of climate change: socioeconomic elements of exposure, sensitivity to that exposure, and adaptive capacity.

of viable technological options for adaptation, the effectiveness of relevant institutions (such as agricultural research and development, markets for goods affected by climate change, forest management organizations, etc.), and the availability of resources, including their distribution across the population (Klein et al., 2007; Yohe & Tol, 2002; Hallegatte et al., 2011). For example, a well functioning public health system would increase the capacity of a society to ameliorate health impacts of heat waves, while well functioning food markets and institutions for agricultural research and development would increase the capacity to ameliorate consequences of climate change for agriculture, including the possibility of taking advantage of outcomes such as lengthening growing seasons and higher CO_2 concentrations that could be beneficial to some crops.

It is also important to note that measures of adaptive capacity alone do not necessarily define the ability of society to adjust to climate change; different social factors such as awareness, attitudes, empowerment, and political will may constrain the deployment and effectiveness of adaptive measures.

Figure 3.1 shows five SSPs occupying different combinations of challenges to mitigation and adaptation, spanning a wide range of possible development pathways. SSP 1 in the lower left corner, for example, indicates a future in which challenges to both mitigation and adaptation are low. By contrast, SSP 3 indicates a future in which challenges to both are high. The number and location of these SSPs are for illustrative purposes because the most appropriate number and characterization of the SSPs remain to be decided by the scientific community.

To keep the number of scenarios manageable, it will be necessary to simplify the complexity of drivers of mitigative and adaptive capacity. Indeed, the world can have a low capacity to mitigate for many – unrelated – reasons (e.g. low institutional capacity or high availability of low-price fossil fuels). The same is true for adaptive capacity (e.g. low institutional capacity or slow reduction of extreme poverty in developing countries). In an initial phase and to avoid over-constraining research groups, it may be useful to keep open the options for specifying the challenges to mitigation and adaptation for a particular SSP.

An important question is whether some of the locations in this scenario space are a higher priority to explore than others, and if so, for which purpose. For example, SSPs 1-3, lying along the diagonal from the lower left to upper right, represent futures in which socioeconomic challenges to mitigation co-vary with challenges to adaptation. In contrast, SSPs 4 and 5 indicate futures in which challenges are high to either mitigation, or to adaptation, but not both. It is possible that the drivers of these challenges are more likely to co-vary, which would favour focusing on the SSPs along the diagonal, but this question remains to be explored. In many cases, the determinants of mitigative and adaptive capacity are similar and can be conceptualized as a more general "response capacity" (Klein et al., 2007; Tompkins & Adger, 2005). For example, human and social capital are important determinants for both. On the other hand, these capacities need not share the same determinants (Hallegatte et al., 2011), and furthermore the challenges to mitigation and adaptation as conceptualized here include not just response capacity, but also other elements of development pathways such as those that would lead to high reference emissions or to high levels of sensitivity to climate change.

A further consideration is that the SSP should set the boundary conditions within which regional and sectoral variation could occur. For example, some pathways might envision response capacities that are low in some parts of the world and high in others, or that transition from one state to another over time. An additional consideration is that some futures may not be the most plausible outcomes, but nonetheless may be equally (or even more) important to explore given their potential consequences.

Finally, it is important to consider, to the extent possible, the plausibility of SSPs against the backdrop of climate change that they potentially imply in the reference case. Particularly with regard to SSP3, the plausibility of a simultaneous combination of high reference emissions (reflecting a challenge to mitigation and correspondingly strong climate change signal) and high climate damages given the large challenges to adaptation can be questioned, but not excluded a priori. It may require assuming strong lock-ins in the energy sector, ineffective governance structures, and only a moderate (or even negative) impact of climate damages on emissions (e.g. because adaptation is done using highly energy consuming options like desalinization, air conditioning, and increased-input agriculture). A full plausibility check closing the loop from emission drivers to climate damages will only be possible after combining the socioeconomic reference scenarios based on the SSPs with climate impact assessments that would also draw on the SSPs. The feedback of climate change onto the SSPs can only be addressed in a preliminary and qualitative manner during the time of SSP construction. However, even if futures such as SSP3 may not turn out to be the most plausible, their investigation will be highly relevant for developing a deeper understanding of the interplay between mitigation, adaptation, and residual climate impacts.

3.3 Dimensions of the SSPs

Although the SSPs are differentiated on the basis of socioeconomic challenges to adaptation and to mitigation, they are characterized by a series of determinants of these outcomes (regarding, e.g. population, economic development, technologies, preferences). Some of these dimensions will be expressed in narrative terms, while others will be quantitative in line with the underlying narrative. The process of constructing and evaluating SSP candidate proposals will inform the detailed descriptions of the dimensions of an SSP. Here we restrict ourselves to defining the characteristics that an SSP will need to exhibit.

An SSP comprises the assumptions about the main determinants of the global scale socioeconomic reference development in the 21st century. SSPs have the following key characteristics:

1. A focus on the description of global and long-term trends.

2. A narrative of future global development that provides a point of reference for elaboration of global assumptions that also are relevant for local- and regional-scale scenarios.

3. Incorporation of information typically used as input assumptions by integrated assessment models of the global energy-economy-land use system, or by global scale climate impact models of different economic sectors. At a minimum, this includes assumptions about future demographics, economic development, and degree of global integration. Such assumptions will likely involve quantitative pathways for population and economic growth.

4. Qualitative and quantitative content sufficient to distinguish SSPs from each other in terms of their challenges to mitigation and adaptation.

5. Clear distinction from a single or best-guess socioeconomic reference scenario. An SSP should restrict itself to key determinants of future global development and not comprise the full manifestation of the future development as captured in a scenario. As a practical guideline, an SSP should not include variables that constitute standard output of integrated assessment models (such as the precise mix of technologies used in the energy sector).

6. Restriction to assumptions that do not include new policies and measures directly motivated by climate change, or their effect on other variables. An SSP refers to socioeconomic reference development of a world without future climate policy. The dividing line between climate policies and other policies can sometimes be difficult to draw; useful approaches are discussed in Section 4, including how to treat currently implemented climate policy measures. If these policy measures are significant enough to affect observed global trends, they would need to be included in the reference assumptions.

Based on these characteristics of an SSP, a number of possible dimensions have been suggested to be included:

- **Demographics**
    - Population total and age structure
    - Urban vs. rural populations, and urban forms
- **Economic Development**
    - Global and regional GDP, or trends in productivity
    - Regional, national, and sub-national distribution of GDP, including economic catch-up by developing countries
    - Sectoral structure of national economies. In particular, share of agriculture, and agricultural land productivity
    - Share of population in extreme poverty
    - Nature of international trade
- **Welfare**
    - Human development
    - Educational attainment
    - Health
- **Ecological factors**
- **Resources**
    - Fossil fuel resources and renewable energy potentials
    - Other key resources, such as phosphates, fresh water etc.
- **Institutions and Governance**
    - Existence, type and effectiveness of national/regional/global institutions in particular sectors
- **Technological development**
    - Type (e.g. slow, rapid, transformational) and direction (e.g. environmental, efficiency, productivity improving) of technological progress
    - Diffusion of innovation in particular sectors, e.g. energy supply, distribution and demand, industry, transport, agriculture
- **Broader societal factors**
    - Attitudes to environment/sustainability/equity
    - Globalization of life styles (including diets)
- **Policies**
    - Non-climate policies could also be an important dimension of SSPs. These include development policies, technology policies, urban planning and transportation policies, energy security policies, and environmental policies to protect air, soil and water quality, for example. It is possible that SSPs could be specified partly in terms of policy objectives, such as strong welfare-improving goals, rather than specific policy targets or measures.

3.4 "Basic" vs. "Extended" SSPs

The development of SSPs is proposed to take place in two stages. A first stage would define "basic" SSPs with the minimum detail and comprehensiveness required to distinguish SSPs along the axes described in Section 3.2 and to provide useful input to populate model settings and parameters. A second stage would develop "extended" SSPs would build on the basic SSPs greater detail on qualitative and/or quantitative information for sectoral and regional analyses.

The two primary motivations for this two-stage approach are practicality and flexibility. A minimum set of assumptions can be defined more quickly and therefore can be available for use sooner, increasing the possibilities for carrying out analyses based on the new SSPs that could be assessed as part of the AR5. Basic SSPs offer the possibility for early "hands-on" experimentation by a wide range of researchers on extending the basic SSPs in various dimensions. These extensions could be motivated by a number of different needs.

- Experience with developing scenarios based on basic SSPs, including reference, climate policy, and climate change scenarios, may lead to a need for additional information by particular models (or types of models) that is not contained in the basic SSP. This information could include more detail on consumption patterns (convergence, diet, etc.), income distributions, non-climate related policies, specific development strategies, etc.

- Application of basic SSPs in regional and local contexts will likely lead to new demands for information that will make the SSPs more useful for decision-makers. One can view basic SSPs as describing "boundary conditions" that provide the framing for more complex assumptions for regions or sectors, including additional elements of narratives, which could then become part of extended SSPs.

- Extended SSPs could take into account sub-optimalities and imperfections in the socioeconomic scenarios (2^{nd}-best worlds). Some models will be able to produce scenarios in which significant sub-optimalities exist (e.g. large unemployment, market-power in the energy sector, insufficient funding for infrastructure development).

A large number of extended SSPs can be constructed for any given basic SSP. A hierarchical structure comprising a small number of basic SSPs, each associated with a family of extended SSPs, may be useful for several purposes:

- *Structured uncertainty analysis:* The family of extended SSPs should reflect the range of assumptions that are consistent with a given basic SSP, and that are requested as additional inputs for the construction of socioeconomic reference scenarios, e.g. in integrated assessment models or in sectoral and regional studies. It thus can help to explain the range of socioeconomic reference scenarios that can be associated with a basic SSP. When combining the family of extended SSPs with climate policy assumptions, it can also help to investigate the robustness of the climate policy scenarios across the SSP family.

- *Distinguishing different types of socioeconomic reference assumptions:* Combining SSPs with SPAs and RCPrep will transform the quantitative reference pathways in the SSP to their associated pathways in a climate policy situation. Two types of SSP variables may be distinguished for assessing the sensitivity of climate policy scenarios across the full range of the scenario matrix. Variables that vary much less with climate policy (for a given SSP) than with SSP (for a given climate policy), and variables for which this does not hold. It is an open question whether basic SSPs will be dominated by variables of the former type (e.g. population and income) and extended SSPs will take up variables of the latter type (e.g. energy and land use). However, if the construction and investigation of basic and extended SSPs revealed this property, it would add value to the concept of distinguishing a basic SSP and its associated family of extended SSPs.

A possible drawback to the development of a large number of extended SSPs is that it could blur the distinction between SSPs and scenarios. To the degree that extended SSPs become associated with individual model interpretations of an SSP, this distinction becomes less clear. An alternative would be to aim for the development of a small number of extended SSPs for each basic SSP, each of which extended the basic SSP in somewhat different directions, but remained broad enough to support the development of a large number of scenarios based on each extended SSP.

The development of basic and extended SSPs does not preclude producing revised versions of either. After a period of time, assumptions in even the basic SSPs may become outdated or for other reasons require revision; at that time, a second generation of SSPs could be produced.

3.5. Initial Specification of SSPs

The IPCC Special Report on Emissions Scenarios (SRES) is an example of the types of information that are likely to be useful to include in SSPs. For example, the overarching narratives of the SSPs would provide the frame for distinguishing alternative possible futures. The SRES developed four families of socioeconomic futures spanned by the dimension of globalized vs. regionalized development and economic vs. environmental orientation. Box 1 reproduces the description of the narratives from the Summary for Policy Makers of the SRES.

Box 1: Short summary of scenario narratives in the Special Report on Emissions Scenarios (copied from the SPM - Summary for Policy Makers):

- The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

- The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

A similar specification of narratives for the SSPs will be needed in an early phase of SSP construction. The narratives should be chosen such that they cover the space of socioeconomic challenges to mitigation and adaptation (Section 3.2). Box 2 is an illustration of a starting point for such narratives. It is important to note that we are not advocating for a specific number or content of SSPs. The objective of this paper is to suggesting a framework for the construction of new socioeconomic scenarios. The actual formulation of the SSPs and corresponding scenarios are to be a community activity following circulation of this paper (see Section 5).

Box 2: Illustrative example of narratives underlying the SSPs depicted in Figure 3.1:

- SSP 1, in which the world is reasonably well suited to both mitigate and adapt, could be one in which development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and high productivity of land. An analogue could be the SRES B1 scenario.

- SSP 3, with large challenges to both mitigation and adaptation, could be a world in which unmitigated emissions are high due to moderate economic growth, a rapidly growing population, and slow technological change in the energy sector, making mitigation difficult (as, for example, in SRES A2). Investments in human capital are low, inequality is high, a regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.

- SSP2 would be an intermediate case between SSP1 and SSP3, where future dynamics could follow historical trends similar to e.g. SRES B2 scenario.

- SSP 4, in which mitigation might be relatively manageable while adaptation would be difficult and vulnerability high, could describe a mixed world, with relatively rapid technological development in low carbon energy sources in key emitting regions, leading to relatively large mitigative capacity in places where it mattered most to global emissions. However, in other regions development proceeds slowly, inequality remains high, and economies are relatively isolated, leaving these regions highly vulnerable to climate change with limited adaptive capacity.

- SSP 5 as a world with large challenges to mitigation but reasonably well equipped to adapt, could be one in which, in the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels (perhaps similar to the SRES A1FI scenario). Investments in alternative energy technologies are low, and there are few readily available options for mitigation. Nonetheless, economic development is relatively rapid and itself is driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.

Associated with such narrative starting points, trend diagrams for various SSP elements can help sketch out the major dimensions of development pathways for a given SSP, and their differences across SSPs. Figure 3.2 shows an example of such a diagram describing storylines underlying scenarios developed to explore the possibilities and challenges related to global sustainability transitions (Gallopin et al., 1997; NRC, 1999). Combinations of such trends would need to be developed through a collaborative process including experts in integrated assessment modelling, impacts and adaptation, and other relevant disciplines, with care taken to ensure the internal consistency of pathways taken as a group, keeping in mind the intended part of the space of future challenges to adaptation and mitigation to be covered.

Further decisions will be needed about which types of information should be qualitative and which quantitative, within an SSP. The desired degree of freedom to allow for adequate coverage of relevant uncertainties will have to be balanced against a practically unbounded cloud of outcomes ascribed to a certain SSP and overlapping largely with other SSPs. The list of possible elements in Section 3.3 provides a starting point for these considerations. While it is likely that broad features of demographic and economic development futures should be included in quantitative form, many choices remain regarding the assumptions to be made in other areas.

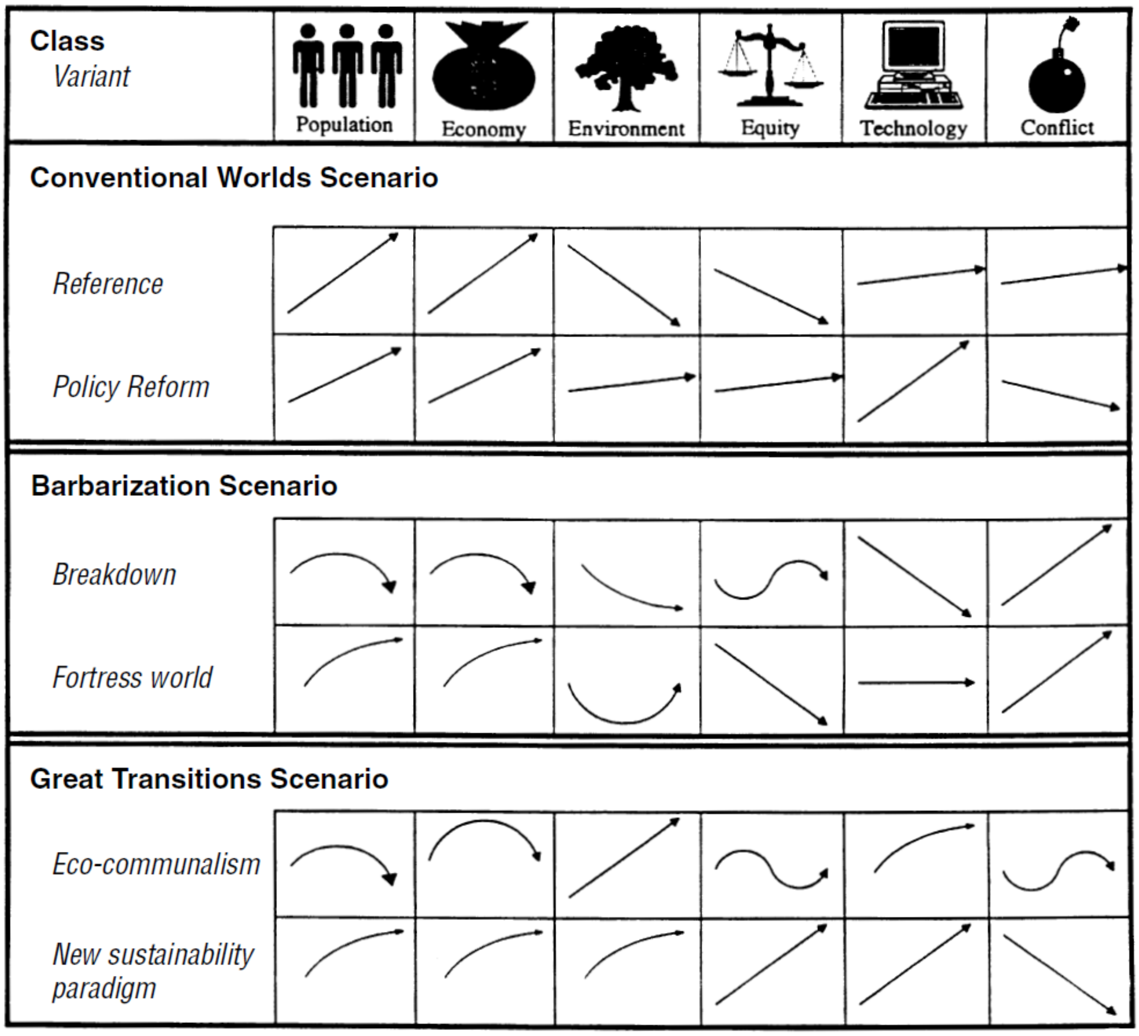


Figure 3.2: Illustrative patterns of change in elements of archetypal global scenarios developed in Gallopin et al. (1997) and assessed by the US National Research Council (1999).

4. Defining the Shared Policy Assumptions (SPAs)

4.1. Introduction

This section discusses information that can be part of climate policy assumptions; analysts developing climate mitigation and adaptations scenarios routinely make such assumptions. Because they often have a strong influence on the scenario, it is desirable to characterize their key dimensions in the same way as socioeconomic reference assumptions are summarized in the SSPs.

Climate policies have two major components: ambition of the climate policy, which is useful to compare results; and actions to promote and support adaptation to the impacts of climate change associated with a particular degree of climate change for a RCP forcing. These policies are explicitly define in a Shared climate Policy Assumptions (SPA).

In terms of mitigation, this package should contain three different types of information (Kriegler, et al. 2011).

1. "First, the SPA should state the global "ambition" of policies, i.e. the policy targets in terms of emission reduction or in terms of stabilization concentration. For instance, a possible SPA ambition is the introduction of policies aiming at a stabilization of CO2 concentration at 450 ppm or of global temperature stabilization at 2°C above its pre-industrial level. This ambition determines the RCP with which the scenario will be consistent.

2. "Second, the SPA should state the "policy and measures" introduced to reach the target: carbon tax, energy tax, international trading scheme, R&D subsidy, norms and regulation, etc.

3. "Third, a SPA should include the "implementation limits and obstacles" that are considered. Examples of generic climate policy assumptions include domestic action on the basis of current ambitions, global coordination on 2 degree or 3 degree stabilization, etc. An SPA may consider an idealized case of all world countries implementing a carbon tax at the same date, or a fragmented international regime with different or zero carbon prices in different regions; it may also exclude or include sub-optimalities in the implementation of policies (e.g., loopholes in regulations). While specification of a limited number of such policy scenarios could be difficult to agree on, it could also provide substantial insight into the robustness of alternative policy designs." (Kriegler, et al., 2011, P. 21)

Even though the ambition of climate policy is sufficient to define in which matrix cell the scenario will be, the other types of information are necessary to insure that it is possible to make appropriate comparisons across models or research groups exploring that combination of SSP and radiative forcing limit, which can facilitate comparison across research results and allow for an estimation of model-related uncertainty.

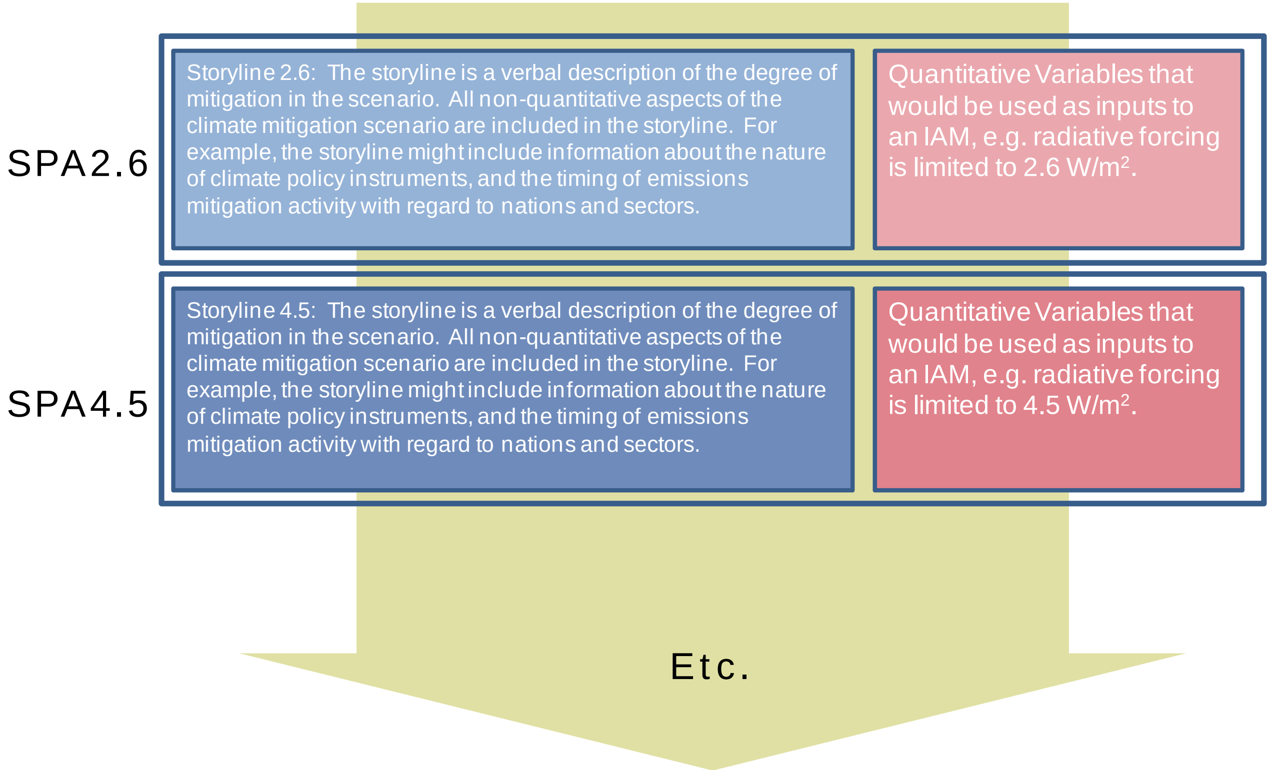
The character of policies that are taken to adapt to climate change could be defined along similar lines. First, different levels of ambition in limiting residual climate damages for given levels of climate forcing may be defined, e.g. in terms of development indicators that should not be jeopardized by climate change. Second, information relevant for policy and measures may include information on global scale factors influencing the availability, viability, and effectiveness of adaptation actions at national and local scales, such as enhanced provision of clean water; enhanced and geographically expanded healthcare provision for infectious diseases; and enhanced investments in coastal defences.

In such instances, the dividing line between policies responding to climate change (part of an SPA) and development policies not directly driven by climate change (part of an SSP) will be sometimes difficult to draw. This will have to be decided on a case-by-case basis. For example, an important consideration in an SSP is the degree to which countries participate in globalization, for example the degree to which world markets for agriculture goods are functioning—are they free market or highly regulated? (This is similar to the global versus local scale axis of the SRES.) But, also the role of temporal and spatial equity concerns are expected to set priorities and weigh alternative policy actions. This orientation will be included in the SSPs and will frame the policies articulated in a SPA package; such as ease of technology transfer and time required to provide universal access to safe water and improved sanitation.

The SPA package itself may include, for example, the availability of adaptation options (e.g. more efficient irrigation techniques or water recycling technologies), and the availability of various amounts of international support for adaptation in developing countries. The range of options can be increased through investments in environmental observations, data collection, research and development, etc.

4.2. Elements of shared climate policy assumptions

Shared climate Policy Assumptions (SPAs) contain qualitative and quantitative information. The **quantitative information** consists of information such as the criteria determining emissions mitigation. In principle information about explicit emissions mitigation could be described in any number of ways. The mitigative stringency could be described in terms of a level of climate change, e.g. transient global mean surface temperature at a given date. They could also be described in terms of a limit to radiative forcing in a specific year, e.g. 2100 and side conditions on the rate of change of radiative forcing. Reaching such targets will require the implementation of policy instruments, e.g. a global or differentiated carbon-equivalent tax. Alternatively, a carbon tax or other instruments may be envisaged without specifying climate a climate target explicitly.



Focusing on radiative forcing as the target level for mitigation allows the climate policy scenarios to be prescribed so as to coincide with the RCPs. How close they should follow the RCP trajectories over time, or in selected target years, is to be considered in the process.

The quantitative portion of the scenarios could include assumptions of the relative prices of non-CO_2 greenhouse gases and greenhouse gas emissions from different sectors. It could also assume different timing for mitigation by region, the magnitude of initial emissions prices when a region first begins emissions mitigation, rules for the allocation of permits in cap-and-trade regimes, and/or carbon values for terrestrial carbon in regions with climate emissions mitigation policies.

The narrative or storyline portion of the SPAs include information that describes the world of climate policies and their evolution over time and across space. It could contain information about the nature of climate policies—preferences for fiscal as opposed to regulatory policies, as well as the timing and application of policies. For example, it could assume the nature of policies to mitigate fossil fuel CO_2 emissions as well as the nature of policies to address land-use change emissions and non-CO_2 greenhouse gases. It could assume different timing of participation of regions and nations in emissions mitigation regimes as for example considered in EMF22 (Clarke, et al. 2009; see also Knopf et al., 2011, Figure 6). It should also include R&D, development, and institutional policies that are implemented to support adaptation, such as the implementation of a technology transfer agreement at the international scale or an international insurance scheme.

The narrative portion of the SPAs should contain information that is instructive to both the integrated assessment modeller trying to develop a scenario, and an IAV researcher trying to understand the nature of the climate policy world co-developing even as climate impacts and adaptation to climate change are transpiring.

4.3. Combining SPAs and SSPs

Climate policy assumptions provide information about (new) climate policies that is excluded from SSPs by their definition as socioeconomic reference assumptions. The dividing line between assumptions on (new) climate policies to be included in SPAs and other policies to be included in SSPs will be difficult to draw in many cases, particularly when it comes to land use and energy policies. It will prove very hard, if not impossible, to establish a convention that would define the climate-relatedness of a policy unambiguously in all instances. We expect that any such convention would evolve over time during the construction and testing of SSPs and SPAs, and their use for the development of socioeconomic scenarios. And it would always be incomplete, as the nature of a policy will have to be judged on a case-by-case basis.

> Nevertheless, it is possible to provide some general guidelines for distinguishing a climate policy that belongs in the SPA and a non-climate policy that belongs in the SSP:
>
> A climate policy is a policy that would not have been implemented if there was no concern about climate change. Any policy that directly constrains or taxes the emissions of greenhouse gases, or that supports greenhouse gas removal or reduction technologies, falls into this category.

In contrast, most development policies such as improving energy access, urban planning, infrastructure, health services, and education are motivated in their own right, and thus are not climate policies. Those policies are part of the socioeconomic reference scenario, and their outline should be included in the SSPs. Such policies may, of course, affect climate policies, or be affected by them, but this does not prevent their inclusion in SSPs. It would only mean that care must be taken when combining SPAs with SSPs to ensure consistency of the full policy package.

In addition, development policy assumptions in the SSPs may have to be adjusted when being combined with an SPA. However, this also holds true for other variables in the SSPs, such as land and energy use patterns that will be affected by climate policy.

There are also borderline cases due to the fact that policies are often derived from multiple objectives and serve multiple purposes. Is a renewable portfolio standard motivated by concerns about climate change or energy security? Does increased disaster preparedness stem from a concern about the increased frequency or magnitude of such disasters in a changing climate, or does it stem from the objective to decrease the vulnerability of the society to present climate variability? Such cases cannot fully be decided, and one may have to resort to ad hoc judgments on a case-by-case basis. The main point is that it is important that the relevant policy assumptions underlying the socioeconomic reference and climate policy scenarios are clearly allocated to either an SSP or a SPA.

One of the most difficult issues may be how to deal with climate policies and measures that are already implemented and affect the socioeconomic development on a larger scale. The price on greenhouse gas emissions in Europe, imposed directly via the European Emissions Trading System (EU ETS), or implicitly via sectoral measures aiming to reach the targets under the Kyoto Protocol, are a case in point. If such implemented climate policy measures are excluded from the socioeconomic reference scenario, it would have already diverged from reality. In order to avoid this, existing climate policies should be part of the reference case. This immediately raises the new questions of what is an existing climate policy (measures in effect like the EU ETS; or a policy foreseeing future measures that is coded into law like the EU Climate and Energy Package)? And how should such policies be projected into the future in the reference case? Ideally, this should be done in a way reflecting the present expectations of market and non-market actors, but those will be hard to discern and characterize. In the framework paper, we cannot do more than flag this issue. The definition of "reference climate policy" or "climate policy as usual" assumptions will be a subject of active discussion during the construction and testing of SSPs and SPAs, and their use in the development of socioeconomic scenarios.

When combining SSPs and SPAs to derive a socioeconomic climate policy scenario, care needs to be taken that their combination is consistent. First, SSPs will contain reference assumptions that are affected by climate policies, and those would need to be adjusted to take into account the information in the SPA. Second, some reference assumptions in an SSP, e.g. development policies, will have implications for climate policy and those assumptions in the SPA would need to be adjusted as well. Finally, the overall narrative in an SSP and the qualitative assumptions in a SPA would need to be broadly consistent. For example, a narrative describing a regionalized development in a fragmented world can hardly be paired with the assumption of a global carbon market. It therefore will be the case that not all SPAs can be combined with all SSPs.

4.4. Extensions of the SPA Concept

The proposed scenario matrix architecture is designed to generate scenarios that have utility in that they allow important comparative and integrative analyses to be performed across all CM, IAM, and IAV communities. The scenarios described in this framework are suitable to be combined with climate model projections for the purpose of informing IAV researchers about the nature of the world as it might evolve over the course of the next century. The explicit introduction of a climate policy dimension as captured in the SPAs offers the flexibility to explore adaptation and mitigation policies for different combinations of SSP, RCP and associated climate change projections. For example, Figure *4.1* shows the combination of RCPs with SPAs describing different levels of adaptation actions for a given SSP. See also the conceptualization of mitigation SPAs in a scenario matrix setting in Knopf et al. (2011; Figure 6).

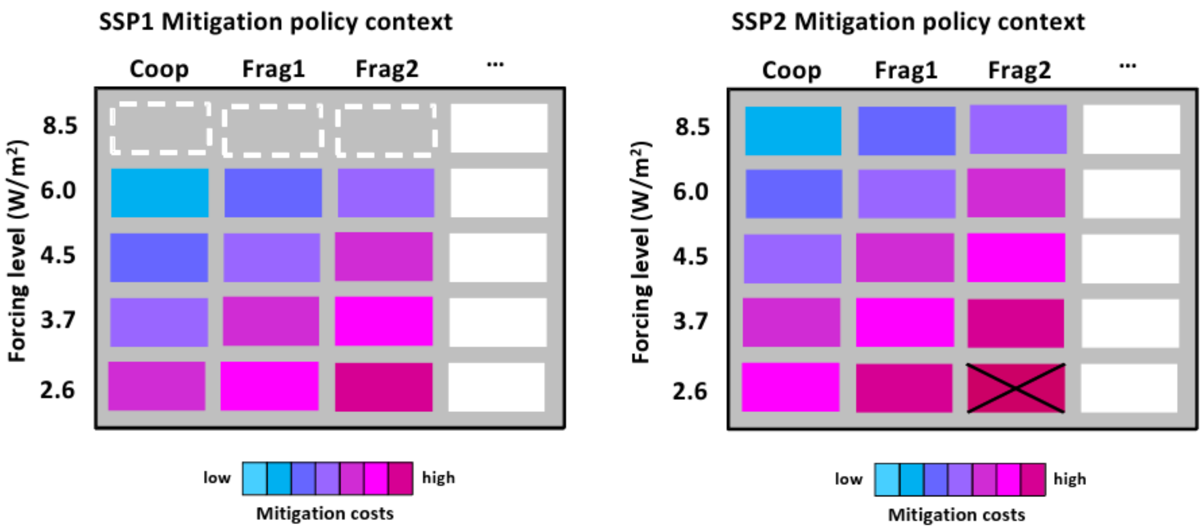


Figure 4.1: A policy axis can be added to the matrix architecture to explore how the costs of mitigation policy depend on assumptions regarding the form of mitigation action. Here, the costs assuming cooperative action (Coop) are compared to policies with different degrees of fragmented participation (Frag1 and Frag2), for SSP1 and SSP2. Some targets cannot be achieved with fragmented participation (indicated by the crosses).

The full SPA will include a consistent set of assumptions on mitigation and adaptation policies (see Figure *4.2*).

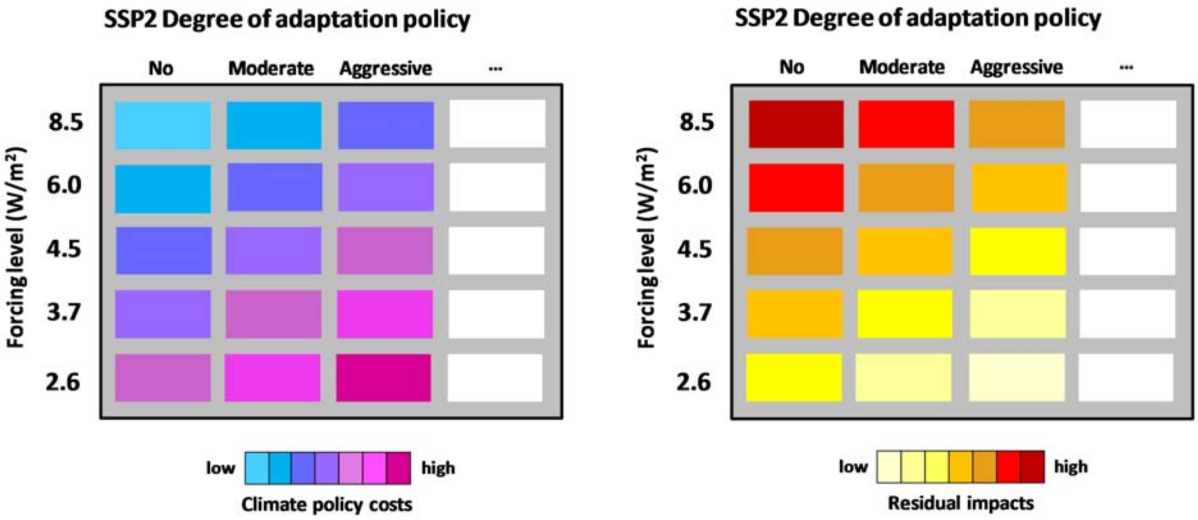


Figure 4.2: The degree of adaptation policy can also be explored within the matrix architecture. Here, adaptation policy is varied from no adaption policy to moderate to aggressive adaptation. The matrix allows for the comparison of the costs and benefits of the policy. The shading for climate policy costs is provided for illustrative purposes only and may change under different assumptions for the interaction of mitigation and adaptation policies.

5. Scenario Process Overview & Timeline

5.1. Status of the new scenario process

Integrated assessment modelling (IAM) teams at IIASA, JGCRI-PNNL, PBL and NIES produced four Representative Concentration Pathways (RCPs) for use in the Climate Model Intercomparison Project 5 (CMIP5). The RCPs reach radiative forcing levels of 2.6, 4.5, 6.5 and 8.5 W/m^2, respectively, in 2100, and were extended to 2300 based on stylized assumptions (van Vuuren et al., 2011a). CMIP5, currently underway, will use the RCPs as an input to produce model ensemble projections of future climate change. These projections will be assessed in the IPCC's Working Group I contribution to the 5th Assessment Report (AR5). The Program for Climate Model Diagnosis and Intercomparison (PCMDI) is making the climate model runs available, as they are ready. Model runs available by the end of 2011 and integrated into the quality-controlled CMIP5 database will be assessed by the IPCC in its 5th Assessment Report.

At the same time, IAV projections continue based on existing emission scenarios (SRES) and climate projections (CMIP3). The IAM community has begun to explore new mitigation scenarios, e.g. in the context of several model comparison activities such as the Asian Modelling Exercise, the Energy Modelling Forum's Project 24 on mitigation technology, and the EU AMPERE project. Individual IAM teams are producing RCP replications, where they study the range of socioeconomic scenarios leading to the various RCP radiative forcing levels.

The construction of SSPs for use by the IAM and IAV communities still needs to be tackled. The following sections outline the steps and timeline needed to produce an operational set of new socioeconomic scenarios incorporating the SSPs. Such a scenario set will facilitate the third phase of the new scenario process, the integration phase. In this phase, consistent climate and socioeconomic scenario information should be employed in IAM and IAV studies.

5.2. Contribution to the IPCC 5th Assessment Report and beyond

A major stakeholder in the new scenario process is the IPCC with its upcoming 5th Assessment Report (AR5). IPCC author teams in the three working groups (WGs) are facing the challenge of evaluating a very large number of studies from the IAM, IAV, and CM communities, and producing an internally consistent assessment that can be meaningfully synthesized across the WGs. Producing information on mitigation, adaptation, and residual climate impacts for a range of climate change outcomes using similar assumptions and across similar temporal and spatial scales will be critical information of relevance for climate policy makers. For this, the IPCC will need a consistent set of climate and socioeconomic scenarios.

The table lays out the timeline of the IPCC's 5th Assessment Cycle. There is considerable overlap between the development of new scenarios and the AR5. Ideally, SSPs and new socioeconomic scenarios need to be available quickly to allow the scientific community enough lead time for meeting the AR5 cut-off dates for eligible publications. Realistically, new socioeconomic scenarios might not become fully available before early 2012 (see timeline below). This is shortly after the 2nd LA meeting of WG II and around the time of the 2nd LA meeting of WG III. Scenarios that are not available by this time will likely not be assessed in the AR5. There is considerable time pressure to produce the new socioeconomic scenarios, and do so without compromising the process. It is expected that much of the literature assessed in the AR5 will be based on previous scenario sets such as SRES and CMIP3.

Table 4: Timeline of the IPCC's 5th Assessment Cycle including cut-off dates for peer-reviewed publications.

	WG I	WG II	WG III
1st LA Meeting	8-11 November 2010	11-14 January 2011	12-15 July 2011
2nd LA Meeting	18-22 July 2011	12-15 December 2011	19-23 March 2012
First Order Draft (FOD)	16 December 2011	11 May 2012	22 June 2012
3rd LA Meeting	16-20 April 2012	22-26 October 2012	5-9 November 2012
Cut-off date for submission of publications	31 July 2012	31 January 2013	11 March 2013
Second Order Draft (SOD)	5 October 2012	1 March 2013	11 March 2013
4th LA Meeting	14-19 January 2013	15-17 July 2013	15-19 July 2013
Cut-off date for acceptance of publications	15 March 2013	31 August 2013	28 October 2013
Final government distribution	7 June 2013	28 October 2013	13 December 2013
Final plenary Approval	23-26 September 2013	17-21 March 2014	7-11 April 2014

Even though there may not be many new socioeconomic reference and climate policy scenarios available for AR5, the scenario matrix approach can prove very useful for assessing the work based on previous scenario sets (see Section 2 for a discussion of the scenario matrix as a heuristic tool). Benchmarking studies comparing the new scenarios with, e.g., the SRES scenarios would help to inform a mapping of research using previous scenarios with the scenario matrix. Such a mapping would allow the assessment to use the scenario process as a heuristic tool to group the existing scenario literature.

The IPCC 5th assessment report will not be the endpoint of the new scenario process. Rather, it may serve a catalyst for a new round of climate change scenario development that will continue beyond the publication of the AR5, and produce scenarios that are likely to be relevant for the period until 2020 - much as SRES has been relevant for the previous decade. It is important to allow the socioeconomic scenario development sufficient time to reach a level of sophistication and integration of IAM, IAV, and CM perspectives that would constitute a major step forward. The timeline of the scenario process should be able to accommodate both objectives - to produce a tangible outcome for the AR5 in the near term, and to move the next generation of climate change scenarios to a new level in the long term.

5.3. Milestones for developing new socioeconomic scenarios

A series of steps and processes will be needed to develop a set of socioeconomic scenarios for use in the IAM and IAV communities.

- **Draft framework paper.** The draft framework paper will be widely circulated to the scientific community, commented upon, revised by the writing team, and finalized. This process will help build support for the socioeconomic scenario process and harmonize conceptual approaches to producing compatible and consistent scenarios. It is recommended that a small panel of review editors oversee the review process. The review panel would work together with the framework paper writing team to ensure that an appropriate process is put in place to adequately take into account the community response in the revision process.

- **Initial proposals and testing of basic SSPs.** The formulation of initial proposals for basic SSPs, comprising socioeconomic reference assumptions, can begin in parallel with circulation of the first draft of the framework paper. The community could initiate the process of socioeconomic scenario development and the identification of basic SSPs. However, before identifying the subset of basic SSPs that will constitute the columns of the SSP-RCP scenario matrix, it is important to test them in integrated assessment models and IAV analyses. The testing phase will begin with the construction of SSP proposals and may involve preliminary socioeconomic scenario development, including IAM reference scenarios with a basic SSP core, socioeconomic scenarios, and climate policy assumptions that establish different RCP levels.

- **Preliminary selection of basic SSPs.** Based on the results of the testing phase, a preliminary set of basic SSPs for the scenario matrix may be selected at the workshop on socioeconomic pathways for climate change research in Boulder, Colorado (3-4 November 2011). This workshop will seek broad participation of the IAM and IAV community. The selected preliminary set of basic SSPs should be published in a special issue of a scientific journal. It is anticipated that the basic SSPs may be revised as the development of socioeconomic scenarios matures (see next item).

- **SSP extensions and socioeconomic reference and policy scenario development.** After the preliminary basic SSPs are determined, the IAM and IAV communities will continue to work on extending the basic SSPs with relevant socioeconomic reference assumptions. Such extended SSPs may include additional quantitative information on e.g. urbanization, poverty, etc., and richer narratives including regional perspectives. Initial discussion of priorities for SSP extensions will take place at the workshop in Boulder, Colorado. The investigation of extended SSPs will involve an iterative process between the formulation of the extended SSPs, the development of socioeconomic reference and climate policy scenarios, a further refinement of extended SSPs, and potential revision of basic SSPs based on a periodic evaluation of what socioeconomic information has proven useful to include. This process of socioeconomic reference and climate policy scenario development will likely proceed over several years. It will aim to produce a set of scenarios that will inform climate policy analysis in the years extending beyond the IPCC AR5 assessment cycle.

- **Illustrative socioeconomic reference and climate policy scenarios**. During the period of SSP extensions, a larger number of socioeconomic reference and climate policy scenarios will be constructed. Although the process will continue for years, it is desirable to identify a subset of illustrative socioeconomic scenarios filling the RCP-SSP matrix at an early stage. Such early illustrative scenarios could still be taken up by a subset of studies prepared for AR5. The decision on illustrative scenarios would ideally be taken together with a decision on the preliminary set of basic SSPs at the Boulder workshop in November 2011.

- **Analysis of development implications of mitigation and adaptation**: Mitigation and adaptation policies will have implications for socioeconomic development. Further work, including scenario work, will be needed to fully understand the socioeconomic implications of climate policies.

5.4. Timeline for finalizing the framework paper

August 2011	Circulation of the draft framework paper to the scientific community. It is desired to establish a review panel to collect the community response and oversee the revision of the framework paper.
16 September 2011	Deadline for submitting feedback, comments, and suggestions for revisions to the review panel.
By end of October 2011	Authors produce revised framework paper with guidance from the review panel, taking into account the review comments and the initial experience gained from the construction of the SSPs.

5.5. Near-term timeline for the development of new socioeconomic scenarios

July - Dec 2011	Initial SSP testing phase. Initial SSPs will be developed and tested in IAM and IAV analyses
7 Oct 2011	Scenario and SSP workshop of the IAMC scenario subgroup to discuss and compare scenario proposals of IAM teams.
from Fall 2011	Socioeconomic scenario development phase. Open call to the community to conduct IAM and IAV analyses building on the basic SSPs for developing extended versions of the SSPs, and socioeconomic reference and climate policy scenarios. This process is likely to continue over several years, and may be reviewed at the time of completion of the AR5 assessment cycle.
3-4 Nov 2011	Workshop on socioeconomic pathways for climate change research at Boulder, Colorado. The workshop will facilitate the implementation of the socioeconomic scenario development phase and ideally select a preliminary set of basic SSPs and illustrative scenarios for use in AR5.
Feb-Apr 2012	Publication of the data of the illustrative socioeconomic scenarios for AR5. These illustrative scenarios are solely dedicated for a small subset of IAV and IAM analyses with the goal of informing the AR5.
First half of 2012	Preparation of a special issue on basic SSPs in a scientific journal.

6. References

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Annex II: Workshop Proposal

INTERGOVERNMENTAL PANEL ON climate change

THIRTY-FIRST SESSION OF THE IPCC
Bali, 26-29 October 2009

IPCC-XXXI/Doc.10
(12.X.2009)
Agenda Item: 3.5
ENGLISH ONLY

SCOPING OF THE IPCC 5TH ASSESSMENT REPORT

Expert Meetings and Workshops

(Submitted by the IPCC Secretariat)

IPCC Secretariat

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WMO UNEP

Proposal for a Joint IPCC WGII/WGIII Workshop on Socioeconomic Scenarios for Climate Change Impact and Response Assessments

Background

During its 25th session (Mauritius, 26–28 April 2006), the IPCC decided that rather than directly coordinating and approving new scenarios itself, the process of new scenario development should be coordinated by the research community, with the IPCC catalyzing the development of and assessing results from a new set of scenarios as part of the Fifth Assessment Report (AR5) cycle. This new set is intended to replace and extend the scenarios used in earlier IPCC assessments, and to be compatible with the full range of available baseline and policy emission scenarios.

These scenarios are referred to as "representative concentration pathways" (RCPs), and were developed with the goals of integrating (a) climate change and earth system models (ESM) projections of climate change, (b) integrated assessment models (IAM) projections of changes in GHG emissions, and (c) projections of impacts, adaptation and vulnerabilities (IAV) under different assumptions about emission trajectories and socioeconomic development.

The research community outlined three phases of scenario development: a preparatory phase and two main phases of scenario development—a parallel product development phase and an integration, dissemination, and application phase. In the preparatory phase, radiative forcing pathways based on four integrated assessment (IA) concentration and emissions scenarios were chosen from the existing literature and provided to climate modellers. The RCPs are in the process of being input into ESM to produce a new set of climate simulations that will be used for mitigation, impacts, and adaptation analyses.

Rationale for an IPCC Workshop on Socioeconomic Scenarios and Storylines

During the development phase, the IPCC Expert Meeting Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies, held in Noordwijkerhout, The Netherlands (19–21 September, 2007), called for the organization of a meeting of the IAM and impact and adaptation communities to develop a joint strategy for storyline development. The need for such a workshop was reiterated by the Task Group established by the IPCC during its 30th session in Antalya, Turkey (21-23 April, 2009) to facilitate the catalytic role of the IPCC.

With the RCPs, climate model simulations are envisioned to be complemented by a "library of socioeconomic scenarios and storylines" to inform impacts and adaptation analyses and IAM emission trajectories in ways that are mutually consistent. While each RCP was generated by an IAM driven by a set of assumptions about future socioeconomic development, technology, and policy, many other alternative sets of assumptions could result in the same concentration/radiative forcing pathway. This flexibility is an intentional and innovative feature of the RCP process. However, the assumptions chosen can significantly affect the outcomes of impacts and adaptation projections and analyses. Consistent scenario definitions of baseline and mitigation scenarios are critical to ensure comparability across studies that will be assessed in the IPCC AR5; this process needs to be initiated soon. An IPCC Workshop involving the relevant communities engaged with the scenario development is necessary to address these issues.

Aims of IPCC Workshop

The overall aim of the workshop is laid down in the Noordwijkerhout report (II.3.2 – New IAM scenarios). In detail this includes:

1. Development of consistent sets of baseline and mitigation scenarios that allows for an assessment of all relevant mitigation and adaptation options. Therefore, baseline and mitigation scenarios will be analyzed in terms of impacts, adaptation needs and mitigation requirements. These alternative scenarios should cover and

lay open the reasonable range of socioeconomic, technological and climate science assumptions and employ the RCPs as benchmark scenarios.

2. Identify the most crucial socio-economic uncertainties and underlying assumptions relevant for baseline as well as mitigation scenarios, such as demographic development, land-use changes, technological change, macroeconomic growth and trade patterns.

3. Exploring a number of (mitigation) scenario which take into account more "real world" mitigation scenarios like the limited availability of certain technologies, delayed participation of crucial countries, sub-optimal design of policy instruments like taxes and emission trading schemes as well as other barriers of implementation.

4. Outline a valid, robust, and consistent approach across the IAM and IAV communities to employing these alternative scenarios that characterize and frame different possible futures in each set of baseline and mitigation scenario.

5. Extract and identify a minimum set of illustrative quantitative socioeconomic trajectories that can be clustered to develop narrative storylines relevant to IAV and IAM ex-post analyses.

Science Steering Group

WGIII Co-Chairs: Ottmar Edenhofer, Ramon Pichs, Youba Sokona; WGII Co-Chairs: Vicente Barros and Chris Field will chair the Science Steering Group. Additional members will be identified from Working Group II and III scientists.

Timing: 2010

Duration: 3-4 Days (IPCC Workshop)

Participants: ca. 70

Trust Fund: 30 Journeys of the 2010's pre-defined budget-line "New Scenarios" are requested.

Annex III: Programme

IPCC Workshop on Socio-Economic Scenarios

Victor's Residenz-Hotel, Berlin, Germany

1-3 November 2010

Agenda Background

An important feature for the upcoming 5th IPCC Assessment Report (AR5) will be improved coherence across the IPCC Working Groups in assessment of projected climate change, its impacts, the degree to which adaptation and mitigation policies can reduce climate change and its impacts, and the costs of action and inaction. Meeting this objective requires successful completion of the process currently under way for developing scenarios incorporating the Representative Concentration Pathways (RCPs) of GHGs and associated levels of radiative forcing. A critical element of this process is the development of a coordinated set of qualitative narratives describing socioeconomic futures and associated quantitative socioeconomic pathways with different implications for societal and ecological vulnerability, and that can be used in combination with the RCPs to facilitate coordinated analyses of climate impacts, and of adaptation and mitigation policies. The goal of the WoSES workshop is to further the development of these socioeconomic pathways and narratives. This document describes the approach for achieving this goal.

The morning of Day 1 will provide context and framing, including an overview of the goals of the meeting; of the current scenario development process and its progress; and of past efforts and current approaches for integrating qualitative and quantitative projections of future socioeconomic development into analysis of climate impacts, adaptation, and mitigation.

The afternoon of Day 1 will focus on the key features and parameters needed in qualitative narratives and quantitative socioeconomic pathways. These discussions will build on the progress made in past meetings, with targeted presentations on key features previously identified and with perspectives from different user communities. The afternoon will conclude with a set of Breakout Group (BOG) discussions of these key features organized around user communities.

The morning of Day 2 will begin with a set of presentations proposing approaches for defining and developing a coordinated set of narratives and pathways that span a range of socio-economic development futures and policy environments, that can be used in combination with multiple climate futures (RCPs), and that are consistent across spatial (e.g. global to regional) and temporal (e.g. shorter to longer-term) scales. A new set of BOGs will build on these proposals and the Day 1 discussions. Two groups will be asked to develop concrete proposals for the key characteristics of a coordinated set of narratives and pathways, one group focused on shorter and one group focused on longer-term climate change impacts and policy decisions. A third group will be asked to propose approaches for linking narratives and pathways across spatial and temporal scales.

The afternoon of Day 2 will commence with presentation and discussion of the BOG proposals, with a goal of agreement on the definition of a set of narratives and socioeconomic pathways. Four BOGs will be formed to each further develop one of these narrative/pathway combinations, and its relationship to the climate futures defined by the RCPs. Day 2 will conclude with presentation of the work of these BOGs.

Day 3 will focus on the presentation of a synthesis of the progress made during Day 2 and a proposal for the process for developing the agreed set of narratives and pathways. The meeting will conclude with discussion of this proposal and decisions on next steps.

PROGRAMME

Monday, 1 November 2010

08:00	Registration
08:30	Welcome Address [Weiß]

Framing (I)

08:40	Scenarios & AR5: Goals of the Meeting [WG II/III Co-Chairs]
09:10	Keynote Presentation: The RCP Scenarios Process [Edmonds]
09:20	Keynote Presentation: Scenario-related Climate Research [Meinshausen]
09:30	Keynote Presentation: Development pathways and lessons from history [Dasgupta]
09:40	Discussion
10:30	Coffee Break
11:00	IPCC Chair: Remarks on Scenarios [Pachauri]

Framing (II) [Ebi]

11:20	Scenario development approach (narratives, pathways) [O'Neill]
11:30	Projecting future vulnerability, impacts, and adaptation [Carter]
11:40	Discussion
12:30	Lunch Break

What do we need in Scenarios?(I) Global trends and drivers [Edmonds]

13:30	NAS Scenario Meeting Outcomes [Moss]
13:40	Technologies [Nakicenovic]

13:50	Demographic and Economic [van der Mensbrugghe]
14:00	Institutions and Governance [Levy]
14:10	Sustainability [Wilbanks]
14:20	Group discussion
15:30	Coffee Break

What do we need in Scenarios? (II) Impacts of drivers in different communities [Pichs-Madruga]

16:00	Impacts perspective [Warren]
16:10	Adaptation perspective [Cohen]
16:20	Mitigation perspective [Riahi]

BOG I: Discussion

17:00	A) Impacts [Wilbanks] B) Adaptation [Hallegatte] C) Mitigation [Mathur]
19:00	Reception

Tuesday, 2 November 2010

Day 1 Summary and Process Proposals [Mathur]

08:30	Summing-up Day 1 [Janetos]
08:40	Paper presentation "Socio-economic Scenario Development for Climate Change Analysis" [Kriegler]
08:55	Paper presentation "Developing new scenarios as a common thread for future climate research" [van Vuuren]
09:10	Comments from WG II/III Co-Chairs Group Discussion
10:30	Coffee Break

BOG II: Socio-Economic Futures

11:00	A) Shorter-term socio-economic futures [O'Neill] B) Longer-term socio-economic futures [Nakicenovic] C) Linking across spatial and temporal scales [Hallegatte]
12:30	Lunch Break

Presentations of results of BOG II (Futures) & Discussion [Mastrandrea]

13:30	Group discussion on socio-economic futures aiming at an agreement on key themes to be described in the resp. narratives and development pathways.

BOG III: Scoping Narratives and Development Pathways

14:30	Several groups, each discussing one narrative and development pathways, and their relationship to different climate futures (RCPs) [O'Neill, Nakicenovic, Hallegatte, etc.]
15:30	Coffee Break

BOG III (continued)

16:00	[O'Neill, Nakicenovic, Hallegatte, etc.]

Presentations of results of BOG III (Scoping) [Zwickel]

16:30 – 17:30	Discussion of straw proposals for the socio-economic futures, and coherence and consistency across the set

Wednesday, 3 November 2010

Preliminary Summing-up & Proposal [Field]

08:30	Summing-up Day 2 [Edenhofer]
09:00	Presentation of straw-man proposal on socio-economic futures and process for further development
09:30	Discussion of proposal
11:00	Coffee Break

Discussion [Edenhofer]

11:30	Discussion of next steps
13:00	Lunch Break

Final Plenary [Edenhofer]

14:00 – 15:00	Discussion of and decision on next steps

Annex IV: Participant List

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