



# The need for and use of socio-economic scenarios for climate change analysis: A new approach based on shared socio-economic pathways

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## ABSTRACT

Socio-economic scenarios constitute an important tool for exploring the long-term consequences of anthropogenic climate change and available response options. A more consistent use of socio-economic scenarios that would allow an integrated perspective on mitigation, adaptation and residual climate impacts remains a major challenge. We assert that the identification of a set of global narratives and socio-economic pathways offering scalability to different regional contexts, a reasonable coverage of key socio-economic dimensions and relevant futures, and a sophisticated approach to separating climate policy from counter-factual “no policy” scenarios would be an important step toward meeting this challenge. To this end, we introduce the concept of “shared socio-economic (reference) pathways”. Sufficient coverage of the relevant socio-economic dimensions may be achieved by locating the pathways along the dimensions of challenges to mitigation and to adaptation. The pathways should be specified in an iterative manner and with close collaboration between integrated assessment modelers and impact, adaptation and vulnerability researchers to assure coverage of key dimensions, sufficient scalability and widespread adoption. They can be used not only as inputs to analyses, but also to collect the results of different climate change analyses in a matrix defined by two dimensions: climate exposure as characterized by a radiative forcing or temperature level and socio-economic development as classified by the pathways. For some applications, socio-economic pathways may have to be augmented by “shared climate policy assumptions” capturing global components of climate policies that some studies may require as inputs. We conclude that the development of shared socio-economic (reference) pathways, and integrated socio-economic scenarios more broadly, is a useful focal point for collaborative efforts between integrated assessment and impact, adaptation and vulnerability researchers.

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## 1. Introduction

The goal of this paper is twofold: identifying current challenges related to developing new socio-economic scenarios and narratives for the analysis of climate change impacts, adaptation and vulnerabilities and for the integrated assessment of climate

response strategies; and offering ideas on how to address these challenges in developing socio-economic scenarios and narratives that can better facilitate integrated assessment and impact, adaptation and vulnerability research, particularly research to be assessed and integrated in the IPCC 5th Assessment Report on climate change.

An effective strategy for developing new scenarios requires careful consideration of the needs of users (e.g., Parson, 2008). Two broad groups of users can be identified: end users, defined as “policy- and decision-makers who use scenario outputs and insights in various decision processes”; and intermediate users, defined as “researchers who use scenarios from a segment of the research community other than their own as inputs into their

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work” (Moss et al., 2008; Section I.3, p. 6). In the context of climate change analysis, the number of different types of users is large and needs to differ significantly across them. End users, for example, may aim to identify robust decisions that would lead to acceptable outcomes across a broad range of futures. A water manager facing a decision about system design in the face of uncertainty in future climate and water demand is a useful illustration. This type of use would benefit from a small set of scenarios derived from a large number of simulation model runs that vary in characteristics to which the particular type of decision under consideration could be sensitive (Groves and Lempert, 2007). However, the choice of such scenarios may prove very specific to the conditions facing each particular agency and the policies under consideration.

In contrast to end users, intermediate users often use perspectives about socio-economic futures individually or in small sets to carry out research on how development pathways might affect, or be affected by, future climate change and our ability to respond to it. Views about socio-economic futures are also used in research as a context for structuring assessments such as those that have been carried out by the IPCC or the *Millennium Ecosystem Assessment* on a global scale. By providing a small number of global-scale scenarios that many studies can draw upon, results across studies can be made more consistent and can therefore be brought together at the assessment stage in a more meaningful way. Researchers working on regional scales have often treated existing global scenarios as exogenous projections, adapted them, and used them as input to derive more detailed scenarios that suited the context and objective of their study. It should also be noted that end users and researchers are often interacting with each other during the scenario building process to jointly assure adequate content and context of scenarios (e.g., Garb et al., 2008).

In this paper we focus on challenges of socio-economic scenario design for intermediate users, that is, for research and assessment. This is not to say that scenarios for end users are less important, but only that their needs are sufficiently different to deserve a focused treatment of their own, which is beyond our scope here. We also focus on scenarios that contain a broadly defined, global framework, rather than those designed to directly address a specific local decision context. These broad global scenarios can and should be refined and linked at the regional and sectoral levels, as we discuss below, so that they can be meaningfully related to issues of adaptation and vulnerability at the local level. However, the overarching global framework would provide a basis for global analyses and serve as a common background against which more focused studies can be carried out. This category of scenarios is envisioned to play an important role in the new scenario process and the next IPCC assessment.

In Section 2 we discuss existing challenges of using scenarios in climate change research analysis, and in particular for integrating research across the integrated assessment modeling, impact/adaptation/vulnerability, and climate modeling communities. We note that socio-economic scenarios and narratives have been used in different communities to different degrees, and have quite different relevance to the dominant modes of research in these areas. Therefore the starting points for new scenario development are very different between the two communities. In discussing these challenges, our goal is to provide a crystallization point for debate on how to advance the development of new scenarios.

The need for new socio-economic scenarios and narratives superseding the previous generation put forward in the IPCC Special Report on Emissions Scenarios (SRES; Nakićenović et al., 2000) has been identified by the research community as well as the IPCC for its 5th Assessment Report (AR5). At an IPCC expert meeting in Nordwijkerhout, the roadmap of a “new scenario process” was laid out (Moss et al., 2008, 2010). This new scenario

process started with a preparatory phase in which integrated assessment modeling teams produced detailed “representative concentration pathways” (RCPs) to be used by the climate modeling teams for their projection of future climate change. However, the subsequent phases of the new scenario process, particularly relating to the development of socio-economic scenarios and narratives for framing the representative concentration pathways in a wider context remain to be operationalized. We briefly discuss elements of the new scenario process in Section 3.

In Section 4 we offer ideas on how a set of “shared socio-economic (reference) pathways (SSPs)”, containing both narratives and quantitative assumptions, could be constructed in a manner that would address several of the challenges we identify in this paper. We explore the usefulness of these ideas for the development of a new generation of scenarios for climate change analysis (for another discussion of ways forward for the development of new scenarios, see van Vuuren et al., 2012).

Section 5 summarizes the insights of this paper, and concludes with a perspective on the short and long-term processes of establishing scenarios that allow the integration of integrated assessment and impacts, adaptation and vulnerability research.

## 2. Key challenges for using socio-economic scenarios for climate change analysis

In this section we consider some of the major challenges in the use of socio-economic scenarios. Understanding these challenges is a precursor to identifying effective strategies for the development of new socio-economic scenarios for use in future research. Here and in the following, we broadly define a socio-economic scenario as a combination of quantitative projections and qualitative information (such as narratives) that jointly characterize a plausible future (Carter et al., 2007). We begin by discussing challenges related to the use of socio-economic scenarios in integrated assessment modeling (Section 2.1) and impacts, adaptation and vulnerability research (Section 2.2), and then turn to the question of how scenarios can be used for integrating work across the different communities (Section 2.3). Due to the complexity of climate change analysis, a comprehensive integration is difficult to achieve by individual cross-cutting studies or by collecting results from independent studies differing in key assumptions and boundary conditions. We therefore raise the question of whether the integration of impacts, adaptation and vulnerability research and integrated assessment modeling requires a shared set of assumptions about socio-economic pathways that can be adopted by both research streams (Section 2.4). In this context, we define a “shared socio-economic pathway” (SSP) as consisting of a parsimonious narrative capturing the key dimensions of the underlying global scale socio-economic development and a collection of quantitative projections for global socio-economic boundary conditions. Parsimonious narratives have been used as a means to convey qualitative information in scenarios for intermediate users (e.g., researchers; see Nakićenović et al., 2000). They need to be distinguished from the use of narratives in scenarios for decision makers, i.e. making scenarios sufficiently realistic and compelling to decision makers.

Such pathways would reflect socio-economic “reference assumptions” describing a world without future climate policy. As discussed in Section 2.5, a variety of analyses will require input assumptions on climate policy as well as socio-economic reference developments. It therefore may be necessary to augment shared socio-economic pathways that describe a world without climate policy with “shared climate policy assumptions” (SPAs).

### 2.1. Using scenarios in integrated assessment modeling

In the analysis of climate change response strategies with integrated assessment models, the development of socio-economic scenarios was driven by the need to specify emissions drivers and trends for the 21st century for projecting future climate change (Nakićenović et al., 2000). This led to a focus on quantitative global and centennial scale scenarios with an increasingly detailed description of trends in greenhouse gases, short-lived species and land use that were taken up by global atmospheric chemistry and climate models (Moss et al., 2008). Integrated assessment research provided scenario-based analysis of climate change response strategies, particularly concerning the mitigation of climate change for achieving climate stabilization targets (see Chapter 2 of the IPCC Working Group III Third Assessment Report and Chapter 3 of the IPCC Working Group III Fourth Assessment Report for overviews). Scenarios were used to structure the space of plausible socio-economic futures. The Special Report on Emissions Scenarios (SRES; Nakićenović et al., 2000), for example, combined a limited set of narratives with a bundle of quantitative socio-economic scenarios to cover the space of global socio-economic futures. In addition, the value of scenarios for controlled comparison of model results and the analysis of model differences has long been widely recognized by the integrated assessment modeling community (e.g., Weyant et al., 2006; Edenhofer et al., 2006, 2010; Clarke et al., 2010). However, the extended use of socio-economic scenarios has also brought new challenges for integrated assessment. They include, e.g., the systematic exploration of the space of plausible socio-economic futures (Morgan and Keith, 2008), the association of socio-economic futures with likelihoods (Schneider, 2001; Nakićenović and Grübler, 2001), the treatment of the (climate) policy dimension in scenario-based approaches (Parson, 2008), and scaling issues as integrated assessment modeling studies are carried out at increasing resolution. Those challenges are relevant for the use of scenarios in climate change analysis in general, and thus are discussed in a broader context in Section 2.3.

### 2.2. Using scenarios in impact, adaptation and vulnerability research

Historically, the impact/adaptation/vulnerability research community has seldom used scenarios of global futures as a basis for analyses of climate change impacts and adaptation potentials. Climate change impact studies have more typically analyzed the consequences of an assumed increment of a climate change parameter (e.g., +2 °C). More recently, considering the heterogeneity and uncertainty of local climate changes, some studies have moved toward vulnerability analysis.

This does not mean, of course, that impact/adaptation/vulnerability research has ignored available global climate change or socioeconomic scenarios (where available) as useful ways to frame impact, adaptation, and vulnerability issues. For example, much of the research on implications of changes in temperature, precipitation, extreme events, and sea-level rise has been informed by discussions in the broader climate research and policy communities about risks of greatest concern, which in turn are informed by both global and regional climate scenarios.

The limited use of quantitative projections of climate parameters from global climate change scenarios in impact/adaptation/vulnerability research (or of contextual conditions from quantitative socioeconomic scenarios), however, reflects several realities (e.g., Rosenzweig and Wilbanks, 2010):

#### 2.2.1. Research style

Because climate change impact assessments need to start with local and sector scale analyses, most of the research community in

most parts of the world is accustomed to working through small-scale individual research rather than larger-group, quantitative model-based projections of initial conditions (in contrast to the climate science and integrated assessment modeling communities). Some parts of the community that are relatively model-oriented are also more scenario-oriented, such as ecosystems, agriculture, energy demand, and food production; but they tend to limit their scenario attention to *climate change* or in some cases, *sectoral development scenarios* (although there have been efforts to develop conceptual frameworks for more integrated impact, adaptation and vulnerability analyses: e.g., Arnell et al., 2004; Lorenzoni et al., 2000). In many cases, the climate change scenarios are regional rather than global. Global socio-economic scenarios such as the SRES have been used more rarely, often for large-scale boundary conditions such as population or GDP (e.g., Arnell, 2003; Parry et al., 2004; Fisher et al., 2005; Nicholls, 2003; Hanson et al., 2011).

#### 2.2.2. Limited knowledge base

Climate change impact and adaptation research deals with particularly complex issues (e.g., uncertainties about ecosystem response to warming, the importance of value judgment in cost assessment, great heterogeneity in impacts and adaptive capacity, a need for local and context-specific analyses, and long-range interactions through world markets). At the same time, in most parts of the world it has had very limited funding over the past two decades. As a result, it very often lacks either the data or the understanding of critical sensitivity parameters required for realistic use of large-scale scenarios and confidence in model results remains limited. In response to this lack of knowledge, most efforts have been devoted to sensitivity analyses as the critical pathways for improving knowledge. For instance, how can one project impacts of a change of temperature of, say, 3 °C, in 2080 without an understanding of how impacted systems change with changes in temperature?

#### 2.2.3. Sensitivity to scenario assumptions

The high sensitivity of impact, adaptation and vulnerability analysis results to contextual assumptions makes it difficult for a classical “causal-chain” approach (from scenario to impacts) to provide useful insights. The emerging perspective of the impact/adaptation/vulnerability community is that managing risks associated with a range of possible impact futures is a higher priority than focusing on a particular impact projection, and attention to relatively low-probability, high-consequence scenarios is often particularly important from a risk management point of view.

#### 2.2.4. Importance of local context

Climate change vulnerabilities and responses depend not only on changes in climate parameters but also on interactions between these parameters and changes over the same periods in local socioeconomic conditions, such as population size and distribution, economic activities, technologies, and institutions (Parry et al., 2007). Where available, socio-economic scenarios have generally been developed at a large scale (e.g., with nationally or regionally aggregated information only) and do not include much of the relevant information for impact, adaptation, and vulnerability research (e.g., detailed localization of activities and clustering of activities). The challenge of producing regional and sub-national scenarios at long timescales has been touched upon by a number of authors (see, among others, Gaffin et al., 2004; Theobald, 2005; Bengtsson et al., 2006; Lempert et al., 2006; Grübler et al., 2006; Groves and Lempert, 2007; Hallegatte et al., 2011; van Vuuren et al., 2010). Local scenarios do exist, such as city scenarios designed to support urban planning. But these scenarios

are not connected to global scenarios, in which global environmental change could be represented. Moreover, they usually consider time horizons of less than 30 years. Urban scenarios with a 2100 time horizon are not generally available so far, yet such scenarios would be of relevance to the understanding of urban-scale climate change impacts.

In a few cases, impact, adaptation and vulnerability research has been related to efforts to develop socioeconomic scenarios to accompany climate change scenarios, often based on regional knowledge. Examples include Berkhout et al. (1999), Arnell et al. (2004), and Rounsevell et al. (2006), and these are promising starting points for further advances in these directions. But the fact remains that there are no commonly shared sets of perspectives about socioeconomic futures across the world as counterparts of global climate change scenarios; and impact/adaptation/vulnerability researchers seldom have resources to develop them to support their work.

Meanwhile, demand has been growing for assessments of impacts and adaptive responses implied by climate change scenarios, especially in IPCC assessments, even if most of the available impact, adaptation and vulnerability knowledge is not directly linked with climate change scenarios or informed by socioeconomic scenarios. The general response has been to extrapolate in order to produce preliminary impact estimates (e.g., IPCC WG II AR 4, 2007; USGCRP, 2010). For instance, if impact research postulates changes in climate parameters, these changes can be associated with changes in those parameters that are incorporated in climate change projections; and impact, adaptation and vulnerability research results that are not scenario-based can thereby be mapped onto scenarios. Much of this work has been carried out at a high level of quality, and it has built a general picture of climate change impacts of relatively modest climate change vs. relatively severe climate change that is viewed by the scientific community with a high degree of confidence, although specific impact projections are better considered illustrative than conclusive. A recent study by the US National Research Council (NRC, 2010) has addressed the painful fact that neither scientists nor policymakers have a clear picture of how the world would be different in the mid to long term under different climate change scenarios.

Given these challenges, prospects for relating impact, adaptation and vulnerability research more often and more directly with climate change scenarios would seem to depend on three factors: (a) developing scenario information that is relevant to concerns of this research, such as information about extreme weather events or improved information about precipitation changes, (b) stimulating knowledge development and cultural changes in the impact/adaptation/vulnerability research community so that interactions with other parts of the climate change research effort are viewed as a higher priority and as adding value, and (c) developing decision-making approaches that understand but are not impeded by uncertainties in using scenario-based impact and adaptation results.

One consequence of these needs is the fact that two parallel and interlinked research lines are needed: one on how impact/adaptation/vulnerability analyses can incorporate global scenarios in their approaches and methods; the other on how global scenario can be developed to correspond to the needs of these analyses. Interactions between impact/adaptation/vulnerability community and scenario development are even more important because local analyses using global socio-economic scenarios will necessarily lead to some inconsistencies between the assumptions (from scenarios) and results. In the development of global scenarios, therefore, it will be necessary to think of how to incorporate new information from local analysis when it becomes available. The idea would be to shift from a linear approach (global scenario

→ local scenario → local impact/adaptation/vulnerability analysis) to an interactive approach in which the local and global scales have two-way interactions.

### 2.3. Using scenarios to integrate climate modeling, integrated assessment modeling and impact/adaptation/vulnerability research

Society has three different response measures to climate change: mitigate, adapt and accept the residual climate damages. Obviously, the question is not what measure to choose over the other, but what mix of measures to adopt. This calls for an integrative assessment of results from all research directions. However, the challenges of bridging the different perspectives, different scales and different needs of integrated assessment modeling and impact/adaptation/vulnerability research are considerable (e.g., O'Neill et al., 2008, and references therein). It is vitally important to assure that these two sets of perspectives do not diverge in the coming years, undermining the consistency of messages to policymakers and stakeholders by climate science. But this ambitious aim can also be an opportunity – to catalyze and strengthen linkages between the two communities – if it is approached in an inclusive and integrative way.

Scale differences present a fundamental challenge to making socio-economic scenarios useful for both integrated assessment and impact/adaptation/vulnerability research. They must be scalable in the sense that even when covering the global scale with necessarily coarse resolution, they allow downscaling (to some extent) to the local context of impact and adaptation analysis. Narratives may offer such scalability, as local constituents may use a global narrative to explore implications for their specific location (e.g., the UKCIP national-scale scenarios; [www.ukcip.org.uk](http://www.ukcip.org.uk)). There is also a strong dependence between spatial detail and time horizon. Spatial detail may be most relevant over shorter time horizons, but can also matter in the long-run (e.g., hydropower dam safety and building construction in flood risk areas). However, the level of detail that can be provided by scenarios will clearly depend on how far into the future they reach. This is discussed in Section 4.1 in greater detail.

Scenarios should ideally cover the range of plausible future developments in a comprehensible (i.e. a small number of scenarios) and at the same time comprehensive manner (i.e. achieving “acceptable” coverage of the space of plausible futures). These two requirements often conflict with each other, particularly when integrating scenarios for mitigation and adaptation analysis. Scenarios must be designed in such a way as to capture a broad range of conditions relevant to both mitigation and adaptation. One approach might be to consider scenarios describing worlds which combine challenges to mitigation that are larger (or smaller) with challenges to adaptation that are larger (or smaller) – an idea we discuss further in Section 4.4. In general, scenario design will need to grapple with the trade-off between scenario detail which may be needed for some analyses and scenario representativeness which will be needed for making statements about uncertainty and robustness. Obviously, the greater the detail of a scenario, the less likely it can serve as a representative for a larger portion of the scenario space (Morgan and Keith, 2008).

The treatment of climate policies in climate change scenarios has been controversial. In economic analysis, policies are generally evaluated against a counterfactual “no policy” case. The counterfactual no climate policy case usually provides the reference scenario for integrated assessment models, which then is compared with a climate policy scenario. In contrast, impact/adaptation/vulnerability researchers have often used a reference present-day case as baseline to compare with scenarios of future socio-economic and climate change, which may include different sets of policy assumptions. Nevertheless, in order to study the



effect of climate policies, it is necessary to separate them from other policy assumptions in the scenario configuration. This is clearly a difficult task given the range of policy contexts from local to global and from adaptation to mitigation. A key question is: How can a meaningful separation of the socio-economic reference and climate policy dimensions be achieved?

#### *2.4. Possible needs for shared socio-economic pathways to construct integrated scenarios in climate change analysis*

A comprehensive exploration of integrated scenarios of mitigation, adaptation and residual climate impacts will require significant contributions from climate modeling, integrated assessment modeling and impact/adaptation/vulnerability research. For the time being, the problem is too complex to achieve such comprehensive integration within individual cross-cutting studies, although such studies will be of great value for fostering an integrated view on mitigation and adaptation. Therefore, the integration will have to rely on a multitude of studies from the different communities which are more or less undertaken in parallel. The obvious question is whether integration of those studies would be feasible if their underlying assumptions are not harmonized to a minimal degree. And if such minimal harmonization is needed, how can it be achieved?

The most apparent possibility would be the specification of scenario elements like quantitative assumptions for socio-economic boundary conditions, representative concentration pathways (RCPs) and narratives to be taken up by all research directions. The necessity of representative concentration pathways for structuring the interface to the climate modeling community has already been recognized, in good part owing to the very practical reason of the computational costs of running fully coupled global climate models. However, can a similar case be made for what we call “shared socio-economic (reference) pathways (SSPs)” to be used by both integrated assessment and impact/adaptation/vulnerability research? As described at the beginning of Section 2, these pathways may include both quantitative socio-economic boundary conditions as well as narratives, adding socioeconomic context to the analyses of drivers, impacts, and responses to climate case.

A case for shared socio-economic pathways would rest on two requirements: that it is possible to develop pathways that are useful both in the integrated assessment and impacts, adaptation, and vulnerability context, and that research based on shared pathways could be assessed in a more integrative way than would otherwise be possible. Shared socio-economic pathways would need to be specified and communicated in a timely and effective manner, and be recognized, correctly interpreted and taken up by both communities. This does not mean that the research needs of either community would be limited to the set of shared pathways, but only that some important common needs to both would be met.

Four different objectives for the use of shared socio-economic pathways can be identified. First, they aim at improving consistency of mitigation, adaptation and residual impact analysis by facilitating the integration of studies with similar assumptions (e.g., on GDP, population, and other socio-economic factors). Second, they can generate new insights by allowing an informed comparison of results. Harmonization of some key assumptions and controlled variation of those assumptions across an ensemble of studies and/or models are very useful, if not a prerequisite, for generating a deeper understanding of the underlying reasons for results and their spread across studies/models. Harmonizing climate policy assumptions will provide additional value. Third, they should facilitate the exploration of the full space of key assumptions that may affect climate change. Uncoordinated

research of the integrated assessment and impact/adaptation vulnerability communities does not guarantee a comprehensive coverage of this space. [van Vuuren et al. \(2012\)](#) demonstrate, for example, that the particular socio-economic scenarios underlying the construction of the four representative concentration pathways do not show a large spread in population pathways. Shared socio-economic pathways can in some instances reduce the risk of settling on a too narrow area of the scenario space, although ‘negotiated’ common scenario assumptions have been often criticized for the opposite: narrowing the range of possible outcomes down to a few cases prematurely. Finally, shared socio-economic pathways should create synergies to enable comprehensive research. It is already common practice in the research community to rely on a set of frequently used assumptions – provided e.g., by public datasets (IEA, World Bank, GTAP) or commonly used scenarios (SRES). With the shrinking relevance of the SRES set of illustrative scenarios, the question emerges whether shared socio-economic pathways could produce new synergies by providing a set of off-the-shelf assumptions useful for and usable by researchers from the integrated assessment and impact/adaptation/vulnerability communities?

We will take up issues in applying and framing shared socio-economic pathways in greater detail in Section 4 of this paper. This includes a discussion of the nature of useful shared socio-economic pathways, how they might be specified, and how they can be related to the broader context of assessments informing climate policy.

#### *2.5. Possible needs for shared climate policy assumptions (SPAs)*

Ideally, in order to separate socio-economic reference developments from the effects of climate policy, shared socio-economic pathways should only include socio-economic “reference assumptions”. This will make climate policy analyses utilizing shared socio-economic pathways more flexible. It allows, e.g., studying the impact of different climate policies for a given pathway, or the impact of different pathways on effects of climate policies

System and policy variables may be placed into four categories. The first category includes variables that are largely unrelated to climate policy, i.e. neither are they significantly affected by climate policy, nor would they affect or reinforce climate policies. An example may be retirement policies. The second category comprises variables directly related to climate policies such as carbon taxes, cap and trade, technology protocols, and adaptation funds. The third category contains variables that have a substantial impact on climate policies, e.g., in terms of counteracting or reinforcing them. An example is health policies lowering the vulnerability of a population to climate change. Urban plans and land-use plans are other good examples. The fourth category includes variables that may be significantly affected by climate policies. An example is international trade policies in a world with fragmented carbon markets. Energy, land use and greenhouse gas emissions are other obvious examples.

Categories 3 and 4 are not mutually exclusive, i.e. variables can be in both or only one of those two categories. Obviously, climate policies (category 2) should be excluded from the socio-economic reference to make it applicable to climate policy analysis. In contrast, key variables in category 3 should be included in order to be able to assess the impact of climate policies imposed on the shared socio-economic pathways. Finally, variables in category 4 would change with climate policy, making the socio-economic scenario a function of both the socio-economic reference and climate policy assumptions. It may therefore be worthwhile to develop a small set of shared climate policy assumptions (SPAs) that could be used in common across a range of studies together with shared socio-economic pathways. The issue of how to specify and use these policy assumptions will be taken up in Section 4.3.

### 3. Socio-economic scenarios and the new scenario process

The traditional linear process of (i) identifying socio-economic scenarios of emissions trends and drivers by integrated assessment modeling, (ii) forwarding them to atmospheric chemistry and climate models to augment them with climate change projections, and then (iii) conducting impact, adaptation and vulnerability analyses on the basis of these scenarios and projections has proven difficult for various reasons, including an inability to “close the loop” from impact/adaptation/vulnerability studies back to socio-economic drivers, inhibition of collaboration across research communities, and length of time required to carry it out. For all these reasons, a new scenario process was initiated (Moss et al., 2008) which abandoned the linear approach in favor of an approach, where all three communities proceed with their analyses (more or less) in parallel.

The new scenario process has been described as a stool with three legs – climate/earth system modeling, integrated assessment modeling, and impact/adaptation/vulnerability research – in which each leg depends for its value and stability on strengths in the other two legs. We believe this is an immensely valuable bridging paradigm, and operationalizing it in any plans for moving forward is a high priority. However, the challenges discussed in Section 2 are very relevant for the new scenario process, and they will need to be tackled if progress is to be made.

A major stakeholder in the new scenario process is the IPCC with its upcoming 5th Assessment Report (AR5). A central question for the assessment will be: for a given climate outcome, what mitigation actions might be required in order to produce this outcome, what will be the potential for adaptation, and what residual impacts might occur? Producing such information for a range of climate change outcomes will be critical information of relevance for climate change policy processes that must weigh the relative costs, benefits (including co-benefits), risks, and un-attended side effects of various levels and rates of climate change. IPCC author teams in the three working groups (WGs) will face the challenge to evaluate a very large number of studies from the different research communities, and to produce an assessment that is internally consistent and can be meaningfully combined across the three working groups.

The roadmap of the new scenario process was laid out in Moss et al. (2008), and summarized in Moss et al. (2010). It consists of three phases – a preparatory, parallel and integration phase. Currently, integrated assessment modeling teams at IIASA, JGCRIPNNL, PBL and NIES have produced the representative concentration pathways for use in the climate model runs, ensuring successful completion of the preparatory phase.

The parallel phase contains four elements. Three of them are well under way. The integrated assessment community has begun developing new scenarios, e.g., within model comparison activities. The climate modeling community has started its climate model ensemble experiment (CMIP5) with exogenous climate forcing specified by the representative concentration pathways. In the meantime, impact, adaptation and vulnerability research based on existing scenarios and projections (SRES, CMIP3) continues. The remaining key challenge, labeled in Moss et al. (2008) as the task of developing storylines, is concerned with injecting a common structuring element in both the integrated assessment and impact/adaptation/vulnerability contributions to the scenario process. Injecting such a common structuring element is particularly useful for the integration of the different research streams. Our discussion of challenges to the use of scenarios (as a structuring element) in climate change research in Section 2 is broadly relevant to the storyline development aspect, and will be taken up in Section 4 of the paper.

Socio-economic scenario information will be employed in the integration phase to inform both integrated assessment and

impact/adaptation/vulnerability studies. Core questions are: How can the climate change patterns produced by the climate models driven by the representative concentration pathways, the socio-economic scenarios produced by integrated assessment models, and the impact/adaptation/vulnerability studies be integrated most effectively? In particular, how can these various strands of work be brought together to provide a coherent view on mitigation and adaptation, and their costs, risks, and benefits, e.g., in IPCC AR5 or other assessment activities? Section 4 will propose some ideas to address the integration challenge.

### 4. Framing and applying shared socio-economic pathways and climate policy assumptions

In this section, we discuss in greater detail what the role of shared socio-economic pathways and climate policy assumptions for integrating impact, adaptation and vulnerability research and integrated assessment modeling might be, and offer some ideas how they might be specified.

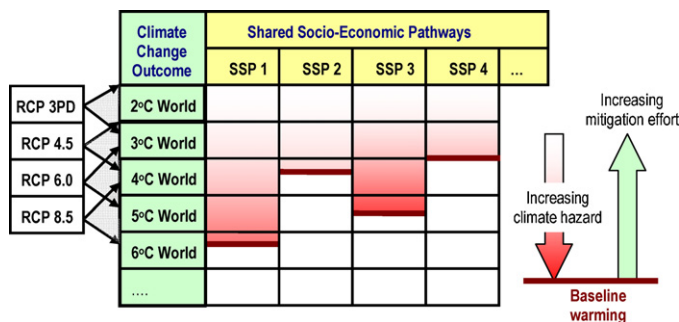
Because shared socio-economic pathways are linked to different needs, their development should begin with input from both communities about features that are essential to them. The development process should move toward agreement on a common set of features that would be shared by the pathways used by both communities and that would facilitate research across community boundaries. It should span a wide range of differences between the systems of greatest interest (e.g., sources of emissions vs. targets of impacts), geographic scales of interest (e.g., global vs. local), and different temporal scales of interest (e.g., the next twenty years vs. the rest of this century). It should work toward a common set of data sources and working assumptions (e.g., about the variables of greatest interest in projecting demographic, economic, technological, and institutional futures). Key questions are: Can shared socio-economic pathways used by both communities be related to a limited number of general types of futures, defined in consistent and broadly understandable ways? If so, how many should be the goal? Defined according to what axes of major determinants?

#### 4.1. Using shared socio-economic pathways for integrating impact/adaptation/vulnerability research and integrated assessment modeling

We first discuss a framework for conceptualizing how shared socio-economic pathways might be used to facilitate such an integration. Based on this framework, we then discuss two related issues: How climate policy assumptions could be related to shared socio-economic pathways, and the appropriate level of detail for the pathways.

Assume for a moment that the identification of shared socio-economic pathways useful to both the integrated assessment and impact/adaptation/vulnerability communities by a process like the one described above would be feasible. One approach could then be to identify or develop a small set of shared socio-economic pathways that would structure the socio-economic space in a manner similar to the way representative concentration pathways structure the range of possible future forcing. Given this set, one can imagine the results of various mitigation and impact studies populating a matrix of combined socio-economic and climate change outcomes.

Fig. 1 presents a conceptual framework for thinking about how climate modeling, mitigation, and impact/adaptation/vulnerability studies could be integrated in a meaningful way. Each cell of the matrix represents a particular combination of climate change outcomes and socio-economic assumptions, and in principle it would contain the results of many studies of mitigation associated



**Fig. 1.** Matrix of socio-economic “reference” developments (characterized by shared socio-economic pathways, SSPs) and climate change outcomes (determined by representative concentration pathways, RCPs). White cells indicate that not all combinations of shared socio-economic pathways and climate change outcomes may provide a consistent scenario.

with achieving that climate outcome, adaptation measures that could be undertaken, and residual impacts. Each row of the matrix could be thought of as a summary of the implications of a given level of climate change on a range of possible future socio-economic conditions. Each column would describe the implications of increasing levels of climate change, or decreasing levels of mitigation effort, for a given set of socio-economic conditions (see van Vuuren et al., 2012, for a related concept). Not all cells of the matrix have to contain a consistent scenario. For example, a shared socio-economic pathway with rapid development of competitive renewable energies, low population growth and environmental orientation would be hard to reconcile with a 6 degree warming, even without climate policy.

The framework presented here would not exclude exploring the implications of socio-economic conditions other than those reflected in the shared socio-economic pathways, just as the development of the representative concentration pathways does not exclude exploring other forcing pathways. However, this framework, and the associated shared socio-economic pathways, would facilitate the development of a critical mass of studies sharing assumptions that are common enough to be able to meaningfully combine their results. Some key dimensions of those studies are likely important enough to anticipate highlighting. For example, the near-term (~2035) and long-term (~2100) time horizons identified would provide a natural dimension for characterizing the results from the literature (see Appendix 1 for a more detailed discussion). Another important dimension is the nature of underlying assumptions about the climate policy environment in scenarios.

#### 4.1.1. Using shared climate policy assumptions together with shared socio-economic pathways

As discussed in Section 2, shared socio-economic pathways are envisaged to refer to socio-economic “reference” developments. This allows greater flexibility to assess the climate policy dimension across and within the shared pathways. The question is whether there is also a need to specify shared climate policy assumptions (SPAs) that may be adopted by a wide range of studies in combination with shared socio-economic pathways.

There are two reasons that shared climate policy assumptions could prove useful. First, a given shared socio-economic will be paired with a wide range of climate change outcomes, some of which, such as the lowest representative concentration pathway, will require a very large degree of mitigation effort. To illustrate this point, we have put an arrow indicating the direction of increasing mitigation effort with decreasing level of climate exposure next to the matrix in Fig. 1. The approach to mitigation in cases with low climate exposure could be a major factor affecting how impact, adaptation and vulnerability analyses

should be carried out. For example, if mitigation requires a large amount of land to be used for bioenergy production or afforestation, this will have major implications for impacts. Thus, it may be useful to ensure that there are enough studies that make common assumptions about mitigation policy in order to compare their results regarding impacts and adaptation.

Second, it may be that shared socio-economic pathways excluding climate policy will not be able to provide the full range of socio-economic information that a large number of mitigation or adaptation studies at the local or regional level may need. Such analyses require assumptions about what is done in the rest of the world, including in terms of climate policies. For instance, mitigation policies implemented in a city or a region will depend on factors like land use, electricity system integration and oil price, which in turn are affected by global mitigation policies. Also, cities or regions may be able to benefit from climate finance instrument created at the international level, allowing them to invest in building retrofit or new public transport infrastructure, and from new technologies developed through support to R&D in other countries. Competitiveness issues may also prevent local actions if the rest of the world does not implement climate policies, and this constraint needs to be accounted for. For adaptation also, what is possible locally will depend on global climate policies, for instance through the availability of funding (e.g., the existence of an international fund providing financial support to adaptation in developing countries), of technologies (e.g., the existence of a technology transfer mechanism at the international scale), and of information (e.g., the existence of an international system to provide at low cost the climate data needed to design adaptation policies). Local analysis may thus require not only shared socio-economic reference pathways, but also shared global climate policy assumptions.

In terms of the matrix representation discussed, the inclusion of shared climate policy assumptions would amount to adding a “climate policy” axis to the climate outcome axis and the shared socio-economic pathway axis in Fig. 1. Since the climate outcome axis already defines the level of ambition of global mitigation policy, there exists of course a close link to the climate policy dimension. This, however, is by no means a one-to-one mapping as many combinations of mitigation measures might yield the same level of warming.

#### 4.1.2. Level of detail of shared socio-economic pathways and relation to marker scenarios

After having laid out a general framework for the application of shared socio-economic pathways, the question remains to what level of detail they should be specified. As discussed in Sections 2.3 and 2.4, an assessment of the relevant uncertainty in future developments requires a broad coverage of the scenario space of plausible futures or at least the spanning of its boundaries. Broad coverage can only be achieved with broad-brush scenario characterizations which would allow categorizing entire groups of more detailed scenarios. Parsimonious narratives can serve such a purpose. Adding quantitative projections as a further element will reduce the generality of a scenario significantly. But if limited to a small set of key variables like GDP, population, and perhaps a few others, it will still be possible to span the space of plausible futures with low, medium and high projections. This approach has been chosen for the development of the representative concentration pathways which were constructed to span the space of the future anthropogenic forcing of climate change. Constructing the shared pathways will present a greater challenge in that the number of dimensions of the space of future outcomes to span is likely to be larger than the single dimension of radiative forcing chosen for representative concentration pathways. Therefore, shared socio-economic pathways will need to contain sufficient detail to allow them to be differentiated along this larger

number of dimensions. Nonetheless, the combination of broad narratives and a very limited set of quantitative low, medium, high projections appears to be the appropriate level of specificity for shared socio-economic pathways. If they provided more detail, they may become overly narrow and not be representative of large regions of the scenario space. If they provided less detail, they may not be distinguishable from each other along all the relevant dimensions of the scenario space, and they may also be missing key information that would be needed by integrated assessment and impact/adaptation/vulnerability research.

It is likely that there will be a variety of studies in need of quantitative input that goes beyond what can be provided by shared socio-economic pathways. It may be necessary to construct more detailed quantitative marker scenarios for these studies to use. Those markers would be derived from model-based analysis and associated with a shared socio-economic pathway. Since it is unlikely that a single marker can be representative for a given pathway, it may be useful to define a second somewhat orthogonal marker scenario in order to signify the idiosyncrasy of individual markers associated with a shared socio-economic pathway. Those markers would also include shared climate policy assumptions and populate the cells of the matrix in Fig. 1, along with other studies employing the shared socio-economic pathways. It is obvious from Fig. 1 that populating each cell of the matrix with one (or more) marker scenarios would lead to a large number of markers that is beyond the scope of most impact/adaptation/vulnerability studies. It therefore will be necessary to identify useful subsamples of markers that highlight the spread of socio-economic and climate assumptions on the most elementary level.

#### 4.2. How might shared socio-economic pathways be specified?

Historically, socioeconomic futures developed for climate change research have consisted of qualitative narrative descriptions of future trends, quantitative assumptions about key socio-economic variables, or both. Approaches that combine narratives with quantitative assumptions (also called the storyline and simulation approach; *Alcamo, 2009*) are most successful when these two elements are carried out iteratively in close collaboration, rather than independent from one another. Each element can inform and constrain the other, and therefore the internal consistency of the scenarios requires an integrative method.

In discussions of socio-economic scenarios in support of the new scenarios process (Section 3), an interest has been shown in taking the four representative concentration pathways as a starting point and developing socioeconomic scenarios to accompany the set of four climate futures. It is quite possible that several different socioeconomic scenarios might lead to a single concentration end point. Although an exploration of these possibilities (already underway in the integrated assessment modeling community) would appear to be of considerable value, the impact/adaptation/vulnerability community may not consider shared socio-economic pathways developed in this manner to be appropriate for their purposes. Rather, socio-economic and institutional conditions known to be important to impact, adaptation and vulnerability analysis could be taken as a starting point for developing shared socio-economic pathways and their narratives, rather than beginning with concentration pathways.

Taking these views into account, here we discuss possible approaches to the development of both qualitative and quantitative elements of shared socio-economic pathways.

##### 4.2.1. Approaching shared socio-economic pathway development through structured views about alternative possible futures

One approach to developing shared socio-economic pathways is by identifying alternative possible futures as frames for discussion

and working back toward rich descriptive narratives and, as possible, related quantitative scenarios. There have been several prominent examples of the use of such narrative-based approaches in scenario development. For example, the work by Paul Raskin and colleagues in the late 1990s on alternative sustainability transitions (*NRC, 1999; Raskin et al., 2002, 2010*), based on earlier work by *Gallopín et al. (1997)* identified three classes of socioeconomic scenarios for responses to sustainability challenges: conventional worlds, barbarization, and great transitions. Each class included two variants: conventional worlds (market forces, policy reform), barbarization (breakdown, fortress world), great transitions (eco-communalism, a new sustainability paradigm). Each of these six possible futures was associated with qualitative assumptions about trends in population, economy, environment, equity, technology, and governance/conflict. The six trends were, in a number of cases, estimated quantitatively in order to assess differences in such implications as resource requirements.

Another prominent example was the international *Millennium Ecosystem Assessment (MEA)*, which developed four alternative scenarios: *Global Orchestration* (globalized with emphasis on economic growth and public goods), *Order from Strength* (regionalized with emphasis on national security and economic growth), *Adapting Mosaic* (regionalized with emphasis on local adaptation and flexible governance), and *TechnoGarden* (globalized with emphasis on green technology). Quantitative models were used to assess differences between scenarios in gains, losses, and vulnerabilities for different regions and populations.

The SRES incorporated demographic change, socioeconomic development, and technological change in developing four families of climate change futures: A1, rapid change and global convergence, emphasizing technological development; A2, regional and local fragmentation; B1, global convergence, emphasizing sustainability; and B2, slower growth based on regional/local initiatives. These families, and subdivisions within them, were associated with quantitative assumptions about rates of population and economic growth, along with some assumptions about land use change (*Toth and Wilbanks, 2004*).

One feature of much of the literature, however, is that the logic of the narratives tends to be global, and challenges in associating them with regional variations have often not been met. An example where the end points were developed at a regional scale to fit regional views of possible futures was the MedAction project, supported by the EC in 2003, which used narratives as stimuli for participative local discussions of alternative futures and associated tradeoffs. It identified three qualitative scenarios: “Big is Beautiful”, “Convulsive Change”, and “Knowledge is King” (*Kok and Rothman, 2003*). Challenges included downscaling regional scenarios to a local scale, relationships to current experience, and constraining local creativity in considering other options.

Several open questions should be addressed in considering a structured approach to narratives. How useful have narratives proven for climate change analysis and assessment? One particular attraction of them may be that they offer scalability of global scale assumptions on regional to local scales in the context of individual impact, adaptation and vulnerability analysis. Have narratives lived up to this promise, and how would they need to be defined for offering such scalability? Finally, is there a way to systematize the intuitive logics approach to defining narratives so that a certain degree of comprehensiveness (in covering the space of plausible futures) can be achieved? An illustrative example is provided in the next subsection.

It is likely that useful shared socio-economic pathways would include not just qualitative narratives, but quantitative specifications of some socio-economic conditions. One approach would be to provide quantifications of these factors at a broad global and regional level – so-called “boundary conditions” – so that more



detailed quantifications could be developed by individual researchers at the local or sectoral level guided by an overarching quantitative framework.

As one example, in 2008–2009, The Energy and Resources Institute (TERI) developed scenarios of socioeconomic change in Northern India for four cases related to permutations of two axes: policy approaches (market mechanisms vs. government policy-driven) and social values (emphasizing economic goals vs. emphasizing environmental goals). The four scenarios were then described by qualitative trends between now and 2050 in seven indicators, each based on a descriptive narrative: demographics, economy, social and cultural changes, conflict, technological change, environment, and governance (see below). Relating these indicators in turn with quantitative information about demographics and economic systems, TERI was able to produce quantitative estimations of differences in requirements by state for such resources as food, water, and energy (Fig. 2).

#### 4.2.2. Developing narratives for alternative possible futures: an example

In general, efforts to date to provide frameworks for thinking about alternative pathways for socioeconomic futures have been related to four major dimensions. *Economic change* may be broadly separated into e.g., rapid growth vs. modest growth and globalized markets vs. more localized systems. *Governmental/institutional change* may be differentiated into, e.g., effective in reaching goals vs. ineffective, democratic vs. authoritarian, and participative vs. top-down. Different directions of *change in social values* may be, e.g., economic consumption vs. nature–society balance and social cooperation vs. conflict. Finally, *technological change* can be, e.g., significant, transformational, and green vs. slow and unequally distributed.

If a convenient framing would be based on two dimensions, which can be used to frame narratives about four different kinds of socioeconomic futures, one approach would be to use an economic dimension and a governance/institutional dimension, as in the case of the TERI scenarios of socioeconomic change in Northern India. The economic dimension would range from rapid economic growth through a globalized economy on one end of a continuum to modest economic growth based on localized systems on the other end, with technological change incorporated in the rate of growth. The institutional dimension would range from effective goal achievement and problem-solving in achieving development goals, with effective leadership and constituency support and cross-institutional cooperation, on one end of a continuum to institutional weakness, instability, fragmentation, and lack of cooperation and consensus on the other end, with social values incorporated in institutional performance.

Another approach might adopt as one dimension the achievement of social and economic development goals, for example as conceived by the UNDP Millennium Development Goals, which are aimed at cutting world poverty in half, saving tens of millions of lives, and spreading socioeconomic benefits to billions of people who are now disadvantaged (UNDP, 2010). One end of a continuum would be achievement of these goals, perhaps not by 2015 but by 2035, while the other end would be no significant progress toward achieving the goals. In a sense, this would move the governmental/institutional dimension toward a more operational conception, related to socioeconomic goals, against which could be set an economic change dimension, including technological change.

These two approaches would not have to be mutually exclusive. For instance, the approach related to socioeconomic goals could be taken as a framing for the relatively near future, while the broader approach could be taken as a framing for the longer term, on into the latter half of the century.

In either case, or in variations on these themes, narratives of four possible socioeconomic futures – HH, HL, LH, LL – would include descriptions of socioeconomic policies implied by such futures: e.g., international cooperation, resource management, and equity. But it would be important to recognize that different policy frameworks and power structures could lead toward the same kinds of socioeconomic outcomes.

#### 4.2.3. Approaching shared socio-economic pathway development through projections of socio-economic variables of interest

Alternatively, one can approach the development of shared socio-economic pathways by identifying a manageable number of socio-economic variables from a consideration of key factors that are often assumed to be exogenous to both integrated assessment and impact, adaptation and vulnerability studies. It seems almost certain that such variables would include projections of demographic change, ideally distribution as well as total size, both regional and urban/rural, and projections of economic activity, ideally sectoral as well as aggregate. Other variables likely to be of interest include projected changes in land use and transportation patterns; changes in energy production and use, including technological innovation and change and considering energy resource potentials; changes in water supply and demand; changes in risk management practices; changes in institutions and governance, including the level of provision of public goods (e.g., education) and possible changes in how citizens view growth, environmental protection, and equity; and changes in information acquisition, access, and use with the evolution of IT technologies and society's response to them. Some of these variables, however, may be more tractable in qualitative narratives than in quantitative scenarios.

| Scenarios                                            | Demographics | Economy | Social and cultural | Conflict | Technological | Environment | Governance |
|------------------------------------------------------|--------------|---------|---------------------|----------|---------------|-------------|------------|
| I – State led economic growth                        | ↗            | ↗       | ↗                   | ↗        | →             | ↘           | ↗          |
| II – Conservative approach with focus on environment | →            | ↘       | ↗                   | ↘        | →             | ↗           | ↗          |
| III – Market driven growth                           | ↗            | ↗       | ↘                   | ↗        | ↗             | ↘           | ↘          |
| IV – Sustainable growth                              | ↗            | ↗       | ↗                   | ↘        | ↗             | ↗           | ↗          |

Fig. 2. Likely trends of development of indicators within each chosen scenario (TERI, 2009).

Analyses of climate policies need to take into account existing market failures in the economic system and cannot assume an ideal world in which markets would be complete and perfect. As a consequence, it would be useful for at least some shared socio-economic pathways to include market failures and provide information about them. Examples include the unemployment level, the tax system structure and its imperfections, the share of informal economy, the barriers to capital flows and trade imbalances, biased saving behaviors, presence or absence of social safety nets (e.g., unemployment insurance and health insurance). Babiker and Eckaus (2007) and Guivarch et al. (2011) show that taking into account unemployment and friction in labor market adjustments can change in a significant way the assessment of mitigation costs. In developing countries in particular, existing economic distortions cannot be disregarded in the design of climate policies. The high level of unemployment (often over 25 percent), the large share of informal economy, and the difficulty to enforce regulation (e.g., in terms of land-use planning) and to raise taxes create specific difficulties that need to be accounted for, even over the long term (World Bank, 2010). In terms of adaptation also, policy analyses cannot assume perfect markets and perfectly rational agents. It has been shown that individuals do not always react rationally when confronted to small probability risks (Kunreuther and Slovic, 1978), and they defer choosing between ambiguous choices (Tversky and Shafir, 1992). Moreover, they have trouble to take into account events that have never occurred before (the “bias of imaginability”, see Tversky and Kahneman, 1974) and they do not always adequately take long and very long-term consequences into account (for public decisions, see Michel-Kerjan, 2008; for private decisions, see Kunreuther et al., 1978). A consequence of these imperfections is that the most effective policies to reach a given objective can be very different from those suggested by a first-best world analysis.

The determination of variables to be included in the shared socio-economic pathways would need to be the product of an intensive discussion between integrated assessment and impact/adaptation/vulnerability researchers. This process would need to be not only collaborative but iterative as well. Initial brainstorming is likely to yield a large number of candidate factors for quantification, at a range of possible scales. Narrowing this list to a manageable number, and then combining assumptions into a small set of shared socio-economic pathways, would follow. The process would need to be iterated after considering whether the sets of variables covered a sufficient range of socio-economic development (e.g., population growth and economic growth) and whether the logic of their combinations was sound.

The fundamental question for exploration in the development of shared socio-economic pathways is whether there is a set of socioeconomic factors that would meet needs of both integrated assessment modeling and impact/adaptation/vulnerability analysis, perhaps nested among a larger set of factors that might differ in their relevance between the two research directions or between regions. Do these sets of socio-economic factors bundled into shared socio-economic pathways lend themselves to a comprehensible (i.e. small number of shared pathways) and fairly comprehensive exploration of the space of plausible socio-economic futures? What will be the logic for selecting a small set of shared pathways from the many combinations likely to be plausible? These questions will be addressed in the next section.

#### 4.3. Relating shared socio-economic pathways to broader contexts of assessment needs

Regardless of the approach taken to specify shared socio-economic pathways, it will be necessary to have some means of deciding whether a given set of pathways is sufficient and

appropriate to serve as a basis for a wide range of climate change analyses. A large number of socio-economic futures are possible to specify; which ones would be best to include in a small set of pathways cannot be decided without some explicit criteria in mind. As a catalyst for discussion, we propose an approach to judging whether a set of shared socio-economic pathways is sufficient that begins with the fact that the scenarios will be used for both mitigation and impact/adaptation/vulnerability studies. How challenging it may be to reduce emissions in order to achieve a particular climate change pathway depends strongly on socio-economic conditions assumed to prevail. Similarly, how difficult it will be to adapt to the climate change implied by that pathway, and what the effect of impacts will be on society, will also depend crucially on assumptions about future socio-economic conditions. Therefore, a set of shared socio-economic pathways should be designed in such a way that it captures a wide range of conditions relevant to both mitigation and impacts, adaptation, and vulnerability. In this way, the shared pathways will facilitate the development of a literature that explores a wide range of uncertainty in the implications of any given future climate change path (such as those implied by the representative concentration pathways).

##### 4.3.1. The space of socio-economic challenges to mitigation and adaptation

To this end, we propose considering whether any given set of shared socio-economic pathway would span a space defined by two dimensions: socio-economic challenges to mitigation and challenges to adaptation (see Fig. 3). Coverage of the full set of possible combinations would facilitate internally consistent analyses that covered the range of uncertainty relevant to both mitigation and impact, adaptation and vulnerability issues.

Mitigation is more difficult if unabated emissions are high, and if the capacity to mitigate is low; therefore, by “challenges to mitigation”, we mean pathways whose socio-economic assumptions are ones that, in the absence of climate change policy, would lead to relatively high emissions and technological, institutional or other conditions that were poorly suited to implementing emissions reductions. Adaptation is more difficult if exposure and sensitivity to climate change are high, and the capacity to adapt is low. By “challenges to adaptation”, we mean socio-economic conditions that, in the absence of climate-related policies, lead to higher vulnerability and less capacity to adapt to a given level of climate change. We use the term vulnerability as defined by IPCC (2012) as, “the propensity or predisposition to be adversely affected”. The term adaptive capacity refers to adaptation defined as “In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities”. Importantly, we exclude

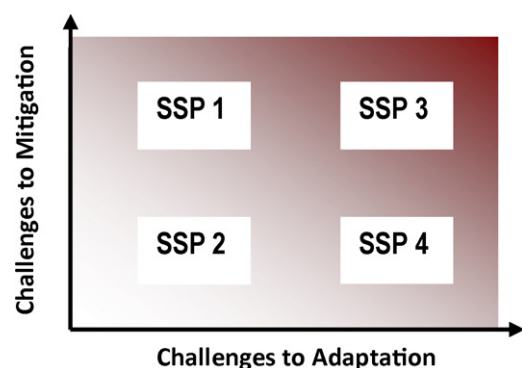


Fig. 3. Example of four shared socio-economic pathways (SSPs) spanning the space of challenges to mitigation and adaptation.

the level of climate change from our definition of adaptation challenges, because shared socio-economic pathways are intended to be paired with a variety of different climate change outcomes and should not therefore include the level of climate change as part of their own definition.

Four shared socio-economic pathways are located within the space shown in the figure for illustrative purposes. For example, SSP 3 represents a world that faces large challenges to both adaptation and mitigation, while SSP 2 is a world in which these challenges are more manageable. SSPs 1 and 4 represent worlds in which challenges are large for either mitigation or adaptation, but not both. A set of shared socio-economic pathways with these characteristics (see next subsection for an example) would cover a wide range of conditions relevant for consistently analyzing the implications of mitigation, adaptation, and impacts across a range of climate outcomes.

The framework proposed here can provide guidance to the choice of shared socio-economic pathways combining narratives and a small set of socio-economic factors by ensuring broad coverage of possible futures most relevant to both mitigation and adaptation. There are several important aspects to this approach. First, the dimensions “challenges to mitigation” or “challenges to adaptation” do not strongly constrain any individual socio-economic factors that might be considered for inclusion in a shared socio-economic pathway. For example, high energy demand associated with a large challenge to mitigation could be consistent with a wide range of future population growth, economic growth, or urbanization futures considered individually. However, the two dimensions do constrain *constellations* of socio-economic factors. Combining high economic growth, rapid urbanization in developing countries, and energy intensive lifestyles would, as a group, be consistent with a world in which energy demand was high. Choosing constellations of factors would be further constrained by jointly considering their implications for vulnerability and adaptive capacity as well.

Second, the two axes are not necessarily independent. Some elements of the shared socio-economic pathways are likely to have implications for both mitigation and adaptation. Independence of the two axes is not strictly necessary for the approach to be useful, and the degree to which the two challenges overlap will to some extent remain a question to be answered by the new scenario process itself and related studies.

Finally, although this approach envisions narratives informed by *challenges* to mitigation and adaptation, rather than mitigative and adaptive activities themselves, there is likely some degree of overlap which may make it difficult to disentangle reference and policy effects, complicating the interpretation of the shared pathways.

Referring to the matrix in Fig. 1, the general idea would be that this set of shared socio-economic pathways could be combined with various climate outcomes and their associated representative concentration pathways to assess mitigation and impacts/adaptation possibilities. The degree to which different SSP–RCP–climate change outcome combinations would be consistent would remain

a research question. For example, one climate realization of RCP8.5 might lead to 3 or more degrees of warming by 2100, and this outcome would probably be consistent with SSP 1, in which the world would be reasonably well suited to adapt, but would find it difficult to mitigate emissions; both of these conditions could plausibly lead to a world willing to accept a relatively large magnitude of climate change. However, it is harder to envision this representative concentration pathway and level of warming being combined with SSP 4; a world that would face difficultly adapting but would have a number of options to mitigate emissions is unlikely to be one that would allow emissions to grow at a rate that would produce the high radiative forcing of RCP8.5.

To locate the shared socio-economic pathways in the space of mitigation and adaptation prospects, the mitigation/adaptation challenge axes would need to be specified in terms of specific variables that would constitute these broad measures. In Table 1 below we indicate just a few that might be considered (Klein et al., 2007; Wilbanks and Sathaye, 2007; Wilbanks et al., 2007; Yohe, 2001). Further extension of these lists would be an important next step in the development of this approach.

#### 4.3.2. Example of narratives for a set of shared socio-economic pathways covering the space of challenges to mitigation and adaptation

To sketch an illustrative example of how four shared socio-economic pathways might fit the space depicted in Fig. 3, SSP 1, 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 was high and most of this demand was met with carbon-based fuels (perhaps similar to the SRES A1FI scenario). Investments in alternative energy technologies and the productivity of land were low. Thus, unmitigated emissions were high, and there were few readily available options for mitigation (including biomass). Nonetheless, economic development was relatively rapid (one driver of high energy demand) and itself was driven by high investments in human capital. Improved human capital also produced 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.

SSP 2, 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 analog could be the SRES B1 scenario.

SSP 3, with large challenges to both mitigation and adaptation, could be a world in which unmitigated emissions were 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 were low, inequality was high, a regionalized world led to reduced trade flows, and institutional development was unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.

**Table 1**  
List of challenges to mitigation and adaptation.

| Challenges to mitigation                                                                                                        | Challenges to adaptation                                                                                              |
|---------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| High demands for energy services and land use changes related to social and economic development aspirations                    | Limited research and technology development on climate change adaptation                                              |
| Relatively low cost of fossil energy forms                                                                                      | Limited knowledge of costs, benefits, prospects, and limits of adaptation options                                     |
| Large inertia in energy supply technology portfolios, together with limited capacities to reduce carbon emissions significantly | Limited evidence of effectiveness of options to adapt to climate change, because attribution is just emerging         |
| Slow progress with realizing energy efficiency potentials                                                                       | Limited adaptation capacities, especially in some developing regions                                                  |
| Limited political will to enact significant mitigation policy initiatives                                                       | Concentrations of population and economic activity in vulnerable areas, in some cases because of maladaptive policies |

Finally, 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 proceeded slowly, inequality remained high, and economies were relatively isolated, leaving these regions highly vulnerable to climate change with limited adaptive capacity.

#### 4.4. Development and use of shared climate policy assumptions (SPAs)

As explained above, shared climate policy assumptions (SPAs) are a means to better separate the climate policy dimension from the socio-economic “reference” dimension reflected in a shared socio-economic pathway. To allow, e.g., for a local analysis, especially on impacts and vulnerability, shared socio-economic pathways may have to be complemented with assumptions about global and national scale mitigation and adaptation policies, and socio-economic variables that are directly affected by it. Local vulnerability will depend on whether ambitious mitigation policies are in place not only through its effect on the magnitude of climate change. For instance, a region might be more or less vulnerable to an increase in air-conditioning energy demand, depending on its energy mix, which will be affected by global climate policies. Also, the global oil price is likely to be different if mitigation efforts are widespread. Local vulnerability will also depend on global-scale adaptation policies, e.g., through the availability of adaptation international financial support. If a selected set of climate policy assumptions can be shared between studies, it will allow for better integration of and comparison between sectoral and regional studies, and to investigate how local policies are influenced by global policies.

As discussed in Section 4.1, shared climate policy assumptions should first and foremost include policies that are implemented because of climate change, aiming either at adaptation or mitigation. Global policies that are implemented for reasons other than climate change, but are directly affected by climate policies constitute a complicated case. The change in these policies due to the implementation of climate policies may be best included in shared climate policy assumptions. An example is the amount and structure of development aid. This aid may not be directed primarily toward adaptation and mitigation but its amounts will clearly be influenced by climate change considerations. All other policy variables should be included in shared socio-economic pathways. This includes global policies implemented for reasons that are not related to climate change, but with obvious consequences for vulnerability, adaptation and mitigation. Of course, it will sometimes be difficult to draw a clear line between climate-related policies and other types of policies (e.g., adaptation and risk management; mitigation and energy policy).

As far as they relate to mitigation, shared climate policy assumptions can be defined in three main dimensions. 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 climate policy ambition is the introduction of policies aiming at a stabilization of CO<sub>2</sub> concentration at 450 ppm or of global temperature stabilization at 2 °C above its pre-industrial level. Second, the climate policy assumption 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. Third, a shared climate policy assumption 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. A shared climate policy assumption may consider an idealized case of all world countries implementing a carbon tax at the same date, or a fragmented international regime with different carbon prices in different regions; it may also exclude or include sub-optimality 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.

The ambition of global mitigation policies is closely linked with the level of climate exposure represented by one axis of the matrix in Fig. 1. A “shared mitigation policy assumption” consistent with a given shared socio-economic pathway and a given climate outcome could, for example, be derived from a global-scale integrated assessment model simulation yielding specific manifestations of, e.g., global carbon and energy prices and land-use patterns. This shared climate policy assumption could then be assigned to a cell of the climate outcome–SSP matrix, but it would not be the only conceivable mitigation policy to reach the given mitigation target under a given shared socio-economic pathway. In fact, it might represent as much the idiosyncrasies of a particular integrated assessment model, e.g., in its choice of land use patterns and low carbon energy mix, as the requirements of the target and the underlying shared pathway. To highlight the model dependence in the choice of a “shared mitigation policy assumption”, it will be useful to compare with the results from other integrated assessment models. This will produce a whole array of mitigation policies for a given shared socio-economic pathways and climate outcome. The challenge then is to select a very small number of shared climate policy assumptions that best span the possible variation along a third “climate policy” dimension within selected cell of the climate outcome–SSP matrix. Obviously, the selected “SSP–SPA–climate outcome” combinations need to be limited to a single digit number to be practical. This implies that only a small fraction of cells of the matrix in Fig. 1 can be populated with one or two shared climate policy assumptions.

To highlight the dependence of mitigation policy on the assumptions about available policy levers, implementation limits and obstacles, it will also be useful to run the integrated assessment models under different perfect and imperfect policy scenarios. From an economic perspective, the distinction between “1st best” worlds (i.e. all market externalities can be removed by optimal policy choices) and “2nd best” worlds (i.e. some market imperfections remain even under optimal policy) is another useful concept in this context. 2nd best worlds may comprise such diverse issues like e.g., imperfect labor markets and underemployment (e.g., Guivarch et al., 2011), limited technology availability, market power in the energy sector (e.g., Mathy and Guivarch, 2010), imperfection in world food and natural resource markets, (monetary and nonmonetary) trade barriers, insufficient investments in transport, water and energy infrastructure, governance issues (e.g., absence of land tenure and inadequate risk management practices), regional or socio-category poverty traps, and many others (see Appendix 2 for further explanation). Exploration of 1st best and 2nd best policy differences is an important topic of many integrated assessment model studies that are currently carried out and that will eventually be assessed by the IPCC 5th Assessment Report.

In terms of adaptation, shared climate policy assumptions will be more difficult to define, as no adaptation efficiency metrics is widely accepted. Also, adaptation and development policies are even more difficult to distinguish than mitigation and development policies (e.g., better sanitation systems have positive consequences in terms of population health in absence of climate change, and are also a powerful adaptation action to cope with



more intense precipitations). The intense overlap between adaptation and development policies and measures makes it particularly difficult to distinguish between policies that belong to the SSPs and those that belong to shared climate policy assumptions.

For local-scale impact, adaptation and vulnerability analysis, however, several global adaptation parameters will be important and need to be included in shared climate policy assumptions: availability of international finance to fund adaptation actions; existence and robustness of global insurance and reinsurance markets; availability of adaptation-related technologies and information, including for instance water saving techniques, earth and climate observations and forecasts, and GIS software to support risk management; and existence and functioning of world-scale markets for food, energy, and other climate-related goods and services (including trade barriers and regulations). Like for mitigation, these policies can be assumed perfectly designed and implemented (e.g., international funding really dedicated to adaptation projects) or can include imperfections and sub-optimalities (e.g., non-monetary barriers to access to technologies, due to regulation or lack of information). The 1st-best vs. 2nd-best distinction is thus valid for adaptation as well.

## 5. Conclusion: toward a synthesis of approaches or a shared agreement on framings?

We have presented an assessment of current challenges for the development and application of climate change scenarios, open questions to be addressed, and some ideas how to move forward. Several key points were made in Sections 2 and 3 of this paper. Socio-economic scenarios in combination with climate change scenarios constitute an important tool for exploring the consequences of anthropogenic climate change and available response options. They have been applied for different purposes and to a different degree in various areas of climate change analysis. Integrated assessment modeling has used them to develop GHG emissions scenarios for the 21st century and to investigate strategies for mitigating GHG emissions on a global scale. Analyses of climate change impacts, adaptation and vulnerabilities depend heavily on assumptions about underlying socio-economic developments, but have employed socio-economic scenarios to a lesser degree. This is due to the multitude of contexts and scales of such analyses.

A more consistent use of socio-economic scenarios that would allow an integrated perspective on mitigation, adaptation and residual climate impacts remains a major challenge. Since the integration will have to rely on a multitude of studies from the integrated assessment modeling, climate modeling and impact/adaptation/vulnerability communities, it is vitally important to assure that the different perspectives of these communities do not diverge in the coming years. The development of new socio-economic scenarios can be an important contribution to catalyze and strengthen linkages between the integrated assessment and impact/adaptation/vulnerability communities – if it is approached in an inclusive and integrative way.

The obvious question is whether integration of studies from the three communities would be feasible if their underlying assumptions are not harmonized to a minimal degree. And if such minimal harmonization is needed, how can it be achieved? We assert that the identification of a set of global narratives and socio-economic pathways offering scalability to different regional contexts, a reasonable coverage of key socio-economic dimensions and relevant futures, and a sophisticated approach to separating climate policy from counter-factual “no policy” scenarios would be an important step toward a more integrated use of socio-economic scenarios.

In Section 4 of this paper, we have proposed some ideas for how a small set of socio-economic scenarios combining narratives and quantitative boundary conditions into shared socio-economic (reference) pathways (SSPs) could facilitate the process of integrative research and eventual assessment of research results. Such pathways should be specified in an iterative manner and close collaboration between integrated assessment and impact/adaptation/vulnerability researchers to assure coverage of key dimensions, sufficient scalability and widespread adoption. They can be used to collect different climate change analyses in a matrix defined by the two dimensions of climate outcome (as e.g., characterized by a radiative forcing or temperature level) and socio-economic development as classified by the shared socio-economic pathways. The pathways should be restricted to socio-economic reference assumptions in order to allow for flexibility in analyzing the effect of different climate policies for a given shared socio-economic pathway, or of a given climate policy across a range of different shared socio-economic pathways. Thus, for some applications, shared socio-economic pathways may have to be augmented by “shared climate policy assumptions” (SPAs) capturing global components of climate policies that some studies may require as inputs. Finally, sufficient coverage of the relevant socio-economic dimensions for the analysis of mitigation, adaptation and residual climate impacts may be assessed by locating the shared socio-economic pathways along the dimensions of challenges to mitigation and to adaptation.

We conclude that the development of shared socio-economic pathways and integrated socio-economic scenarios more broadly is a useful focal point for collaborative work between integrated assessment and impact/adaptation/vulnerability researchers. However, it is an open question whether shared socio-economic pathway development should seek a single approach or encourage, at least at the outset, an ensemble of approaches that share common features. This question can be viewed both under a long term (>3 years) and short term perspective (until the IPCC 5th Assessment Report in 2013/2014).

### 5.1. Long-term perspective on scenario development for integrated mitigation and adaptation analysis.

When taking a long term perspective, the focus should be on establishing platforms and processes for collaborative work of integrated assessment and impact/adaptation/vulnerability researchers on integrated scenarios. As mentioned above, the quest for more integrated socio-economic scenarios can be an important catalyst for strengthening the linkages between integrated assessment modeling and impact, adaptation and vulnerability research, but this is likely to be a gradual process. It will involve gradual adjustments of both research cultures toward a more broadly shared understanding of the utility of scenarios and their applications. We envisage that these gradual adjustments can be achieved by running through several iterative cycles of scenario work that allow gaining – with each cycle – greater insight into the nature of useful shared socio-economic pathways and shared climate policy assumptions as well as greater recognition of their value among researchers from both communities. Such a cycle may include individual and initially separate scenario work from local to global scales, including attempts to adapt global scenarios to local contexts, followed by a joint effort on taking stock of the evolving scenario database, its linkages, strengths and weaknesses, and finally – based on the insights gained – a deliberate and collaborative push of integrated assessment and impact/adaptation/vulnerability researchers to develop next generation shared socio-economic pathways and climate policy assumptions on the global scale. This may later on be followed by an attempt to design standardized sets of scenario

assumptions for a variety of national and local scales that are linked to the global scale pathways.

These can then be scrutinized and improved in subsequent cycles. The first phase comprised individual scenario work should provide an extensive test-bed for the usefulness of last generation shared socio-economic pathways and climate policy assumptions. Ideally this includes local, regional and context specific scenario work evaluating the scalability of pathways. It should also test for the inclusion of key dimensions in shared socio-economic pathways, and their coverage of relevant futures.

The collaborative elements of the iterative process require platforms for community interaction that yet need to be established. Such platforms can take several forms, e.g., dedicated working groups of organizations which are recognized by both integrated assessment and impact/adaptation/vulnerability researchers, regional working groups that assure participation of researchers from all regions in the scenario building process and scenario data repositories that are used by both communities. New analytic methods for scenario elicitation could help facilitate such processes (Rozenberg et al., 2011).

In most cases, establishing such platforms needs resources, a common purpose and sense of urgency. In the short term, a sense of urgency and to some extent common purpose is provided by the 5th Assessment Report of the IPCC. This creates a window opportunity to establish institutional structures for collaborative scenario work that may be able to sustain a scenario process even after the AR5 has been finalized.

#### *5.2. Short term goals for integrated scenario development in the context of the new scenario process and aiming to inform the IPCC 5th Assessment Report*

In the short run, an immediate concern is to produce tangible outcomes that would allow the 5th Assessment Report of the IPCC to take a more integrated perspective on mitigation, adaptation and residual climate impacts. The new scenarios process outlines a way forward, aiming for integration of research from different research communities (Moss et al., 2008, 2010). However, the new scenario process has yet to answer a series of important conceptual and methodological questions, and is still struggling to establish a platform for truly collaborative work between integrated assessment and impact/adaptation/vulnerability researchers. One possibility, therefore, is to work toward joint agreement on a shared set of questions to be answered by scenarios and/or narratives, along with a shared sense of socioeconomic and other contextual variables to be addressed. The provision of more integrated scenarios on mitigation, adaptation and residual climate impacts for the IPCC 5th Assessment Report should be widely recognized as an important goal that is shared by both communities. This recognition should help to muster the will for cross-community collaboration on scenario development. Following the approach presented in this article, this would include the development of an over-arching framework for a set of shared socio-economic pathways, basic features of their content, and a process for fleshing out further details. The features should reflect the agendas of each community and include strategies for collaboration in order to assure outcomes that integrate the priorities and perspectives of both communities.

We conclude with a more general observation. In this paper, we discussed many challenges for the development of a new generation of climate change scenarios. We also laid out a set of ideas how to tackle these challenges. Tackling them will be important, because the stakes are high. New scenarios are needed for providing a more integrated perspective on mitigation, adaptation and residual climate impacts on all scales. This in turn will provide a better understanding of the many facets of climate

change, and produce a more consistent picture of available response options. We are confident that the goal is large enough to engage researchers from the integrated assessment and impact/adaptation/vulnerability communities in a serious collaborative effort. If this occurs scenarios will have shown their integrative power in yet another way. They are not only powerful tools for long-term strategic thinking from an integrated systems perspective. They are also powerful tools for initiating and framing a discourse integrating the views of many from different communities.

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#### **Appendix 1. Importance of short- vs. long-term time horizons for scenario development**

The climate modeling community will produce high resolution climate change patterns out to 2035 for the representative concentration pathway stabilizing at 4.5 W/m<sup>2</sup>. This is also a time horizon over which it may be possible to produce more credible projections of socio-economic conditions, such as population and GDP density that may not have diverged substantially from current patterns. Impact/adaptation/vulnerability studies may therefore be able to employ both more detailed climate and socio-economic information than is possible for long-term studies, and with less associated uncertainty. Over a longer time horizon, climate outcomes associated with representative concentration pathways will differ more significantly, and the potential for divergent socio-economic conditions is also greater. Given the difference in uncertainties and in the plausibility of higher resolution climate and socio-economic information, it may be appropriate for shared socio-economic pathways to be defined with different levels of detail for different time horizons. Since the spatial distribution of population and GDP will be tied to the present-day situation for the next decades, common gridded population and GDP scenarios out to 2035 might be a very useful tool for both integrated assessment and impact/adaptation/vulnerability studies. These would need to be built on a harmonized and gridded database of present day (2010) distributions of population and GDP that could be used by integrated assessment and impact/adaptation/vulnerability researchers as calibration point for the base year. In contrast, socio-economic projections out to 2100 are highly uncertain, and long term shared socio-economic pathways should thus be restricted to a few trajectories of fundamental socio-economic variables like GDP and population for large regions. Related questions are: How to harmonize assumptions for the short term (2035) and long term (2100)? How to assure coordination with scenario development in the IAM community? A detailed socio-economic data set for present day (e.g., base year 2010) may be of enormous use for many activities. Should there be a cross-community effort to put such a dataset together?

#### **Appendix 2. A summary of the 1st vs. 2nd best world distinction, and its importance for climate policy analysis**

The feasibility and costs of mitigation and adaptation, as well as the damages from climate change will not only depend on socio-economic reference trends, but also on policy environments that

either nurture or impede the effective and efficient implementation of climate policies. Climate policy analysis often assumes that markets have worked efficiently in the past (i.e. market failures were negligible on a global scale), and are now faced with a climate externality. Resulting optimal policies aim to internalize climate change (by means of greenhouse gas pricing) without any further needs for additional market interventions (like e.g., subsidies for clean energy and regulation). In economic jargon, such situations of isolated market failures that can be removed with a Pareto-optimal policy are called “1st best”, and the resulting optimal policies are called “first-best policies”. A classic example of this approach is the work by Nordhaus (1994, 2000, 2007). Many mitigation cost calculations by integrated assessment models for AR4 were also conducted, more or less implicitly, with a first best philosophy. Such analyses are generally very optimistic about the prospects of climate policy, and there is a strong need to look into so-called “2nd best” situations of multiple market failures (Lipsey and Lancaster, 1956) in greater detail. While a first-best policy removes all market failures, a second-best policy optimizes the outcome given the constraint that one (or some) of the market constraints or failures cannot be removed. The economic terms of “1st best” and “2nd best” should therefore not be confused with normative judgments of the goodness of a policy. In a 2nd best situation, the 2nd best policy is the best one can do. On the other hand, if existing market imperfections (e.g., in the tax structure or in labor markets) can be addressed with climate policy, this may offer the opportunity for reduced mitigation costs. Thus, 2nd best analysis of climate policy will give a more robust picture of feasibility and costs, will allow analyzing additional instruments to carbon pricing, like clean energies subsidies and efficiency regulation, in a consistent framework, and will be needed to identify double dividends and co-benefits of climate policy.

Important additional market failures and other limitations characterizing 2nd best situations include market power in the energy and other sectors (including fossil fuel markets), limited appropriability of private sector innovation (spill-over externality), distortionary taxation, subsidies and regulation, particularly in the labor, energy and agricultural sectors, (under)provision of public goods (transport and energy distribution infrastructure, adaptation infrastructure like levees), limited technology availability due to failures in innovation process or political economy constraints, limited flexibility in carbon pricing regimes, e.g., due to regional or sectoral fragmentation, distorted insurance, capital and land markets, imperfect labor market, with existing underemployment, asymmetric information of firms, households and regulators, trade barriers, and other pollution and resource externalities, including air pollution and overexploitation of natural resources.

More generally, we suggest that the concept of market failure, and a taxonomy of relevant market failures, will be an important dimension for clustering the results on mitigation, adaptation and residual climate impacts in a meaningful and policy relevant manner.

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