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# The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century

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### ABSTRACT

Long-term scenarios play an important role in research on global environmental change. The climate change research community is developing new scenarios integrating future changes in climate and society to investigate climate impacts as well as options for mitigation and adaptation. One component of these new scenarios is a set of alternative futures of societal development known as the shared socioeconomic pathways (SSPs). The conceptual framework for the design and use of the SSPs calls for the development of global pathways describing the future evolution of key aspects of society that would together imply a range of challenges for mitigating and adapting to climate change. Here we present one component of these pathways: the SSP narratives, a set of five qualitative descriptions of future changes in demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources. We describe the methods used to develop the narratives as well as how these pathways are hypothesized to produce particular combinations of challenges to mitigation and adaptation. Development of the narratives drew on expert opinion to (1) identify key determinants of these challenges that were essential to incorporate in the narratives and (2) combine these elements in the narratives in a manner consistent with scholarship on their inter-relationships. The narratives are intended as a description of plausible future conditions at the level of large world regions that can serve as a basis for integrated scenarios of emissions and land use, as well as climate impact, adaptation and vulnerability analyses.

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## 1. Introduction and background

Long-term global scenarios have played a key role in climate change analysis for more than 20 years (Leggett et al., 1992; Nakicenovic et al., 2000; Raskin et al., 2005; van Vuuren et al., 2012). While other approaches to characterizing the future exist (Lempert et al., 2004; Webster et al., 2003), alternative scenarios

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are an important method for exploring uncertainty in future societal and climate conditions (Jones et al., 2014). Scenarios of global development focus on the uncertainty in future societal conditions, describing societal futures that can be combined with climate change projections and climate policy assumptions to produce integrated scenarios to explore mitigation, adaptation and residual climate impacts in a consistent framework.

Often, societal development scenarios consist of qualitative and quantitative components (Raskin et al., 2005; Rothman et al., 2007; Ash et al., 2010; van Vuuren et al., 2012). Quantitative components provide common assumptions for elements such as population, economic growth, or rates of technological change that can be meaningfully quantified and that can serve as inputs to models of energy use, land use, emissions, and other outcomes. Qualitative narratives (or storylines) describe the evolution of aspects of society that are difficult to project quantitatively (such as the quality of institutions, political stability, environmental awareness, etc.), provide the logic underlying those elements of scenarios that are quantifiable (and their relationships to each other), and provide a basis for further elaboration of the scenarios by users.

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

However, the specific content (as opposed to the conceptual framework) of the SSPs and associated IAM scenarios has, until now, not been presented in the peer-reviewed literature. The focus of this special issue is to present that content. The SSPs describe plausible alternative changes in aspects of society such as demographic, economic, technological, social, governance and environmental factors. Like many previous characterizations of future societal development, they include both qualitative descriptions of broad trends in development over large world regions (narratives) as well as quantification of key variables that can serve as inputs to integrated assessment models, large-scale impact models and vulnerability assessments (Alcamo, 2001). In this paper we present the SSP narratives, describing the methods used to develop them, their main features, and open questions regarding their design and use. Along with the narratives, we provide tables that summarize trends in key elements of the SSPs. Other papers in this special issue describe the quantitative elements of the SSPs, including population and educational composition (KC and Lutz, 2014), urbanization (Jiang and O'Neill, 2014), and economic growth pathways (Crespo Cuaresma, 2014; Leimbach et al., 2014; Dellink et al., 2014). An additional set of papers focus on the integration of the narratives and quantitative elements of the SSPs into IAM simulations describing the possible evolution of land use, energy and agricultural systems and

resulting GHG emissions under different SSPs and climate policy assumptions.

Within the conceptual framework for integrated scenarios, the SSPs are designed to span a relevant range of uncertainty in societal futures. Unlike most global scenario exercises, the relevant uncertainty space that the SSPs are intended to span is defined primarily by the nature of the *outcomes*, rather than the *inputs* or *elements* that lead to these outcomes (O'Neill et al., 2014). As such, the design process begins with identifying a particular outcome and then identifies the key elements of society that could determine this outcome. This approach is typically associated with backcasting, where an end state is already in mind as the pathways are being developed, although not necessarily assuming that these states are all desirable (Vergragt and Quist, 2011). Such a backcasting scenario approach has proven effective in focusing on those areas of the uncertainty space that are most important in choosing among alternative options (Groves and Lempert, 2007). Although the domain of application of climate change scenarios includes a large range of specific decision-making situations, they generally cover options to mitigate or adapt to climate change. Therefore, the SSP outcomes are specific combinations of socioeconomic challenges to mitigation and socioeconomic challenges to adaptation (Fig. 1). That is, the SSPs are intended to describe worlds in which societal trends result in making mitigation of, or adaptation to, climate change harder or easier, without explicitly considering climate change itself.

While the focus on challenges to mitigation and adaptation allows for a more systematic exploration of uncertainties relating to climate policies, the SSPs can also be useful in other contexts relating more broadly to sustainable development. This is due to the fact that socio-economic challenges to mitigation and adaptation are closely linked to different degrees of socio-economic development and sustainability, a topic we discuss in Section 4. Thus, the SSPs can be applied to the analysis of sustainable development problems without specific reference to mitigation and adaptation challenges even though these challenges were the starting point for their design. It is, of course, possible that a backcasting approach that took broader sustainable development rather than climate change challenges as a starting point would yield a somewhat different set of SSPs. To this end, the approach taken here for climate change research may provide a useful example for the development and use of new scenarios in sustainable development research.

While the SSPs, and the scenario process more broadly, are intended to be policy relevant (hence the framing in terms of challenges to two types of policy responses), the intended direct

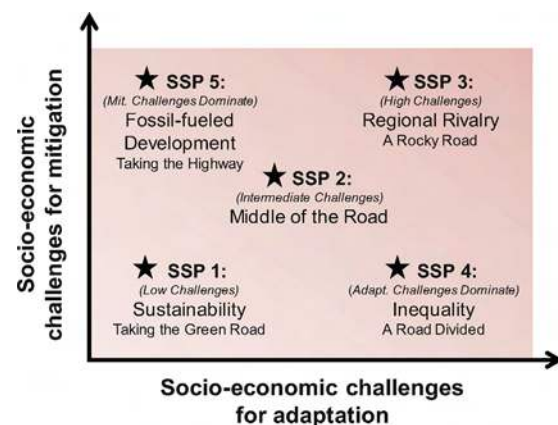


Fig. 1. Five shared socioeconomic pathways (SSPs) representing different combinations of challenges to mitigation and to adaptation. Based on Fig. 1 from O'Neill et al. (2014), but with the addition of specific SSPs.

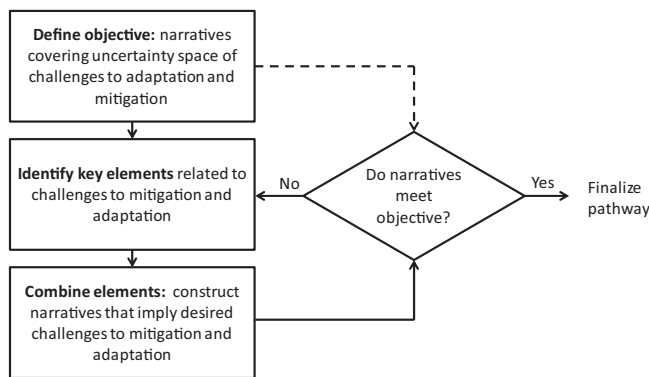


Fig. 2. Flow diagram of process for developing SSP narratives.

users of the SSPs are primarily the research and assessment communities. The framing of SSPs in terms of challenges facilitates research based on the SSPs that collectively can characterize a range of uncertainty in the mitigation required to achieve a given climate outcome, or the adaptation possibilities associated with that outcome. Development of such a research base, and its assessment, is a key goal of the scenario process. Thus, the SSPs are not meant primarily as a direct communication tool for climate policy advice, but rather as a tool to enable the research community to produce effective assessments for climate policy makers. In addition, the SSP framing will facilitate improved understanding of the determinants of challenges to mitigation and to adaptation. The SSPs are developed based on the best current hypotheses about which elements of societal development pathways are the most important determinants of these challenges. Use of the SSPs in impact, adaptation and mitigation studies will test those hypotheses and lead to learning that can be used in future iterations of SSP development.

We consider the narratives presented here to be part of “basic SSPs”; that is, they contain enough information to sketch alternative development pathways that are plausible and that enable them to be located in a particular area of the challenges space. However, for many applications, “extended SSPs” are likely to be required, which would contain additional, more detailed information for particular regions, sectors, or variables (Van Ruijven et al., 2014) or that would be enhanced according to specific needs (e.g. vulnerability and risk assessment tools at national or sub-national level; Birkmann et al., 2013). For example, scenario analyses that focus on a particular national or sub-national region, or on a particular sector (such as water, health, or agriculture), will likely benefit from extending these narratives and their associated quantitative assumptions (Ebi, 2014). Extended SSPs should use assumptions that are consistent with the basic SSPs, but that support modeling and analysis that goes beyond the key variables provided in the basic SSPs.

In Section 2 we describe the development of the narratives. Section 3 presents summaries of the individual narratives (full versions are presented in the Supporting Information), along with thoughts as to how the future societal development pathways they depict could plausibly emerge from current developments. In Section 4 we step back to look at the set of narratives as a whole, noting the key distinctions across the narratives as well as how they relate to other existing global scenario narratives and the broader sustainable development context. Section 5 discusses open questions and concludes.

## 2. Methods: Development of narratives

The development of the SSP narratives was driven by three considerations: (1) the general purpose of narratives of societal

development in the context of climate change scenarios; (2) the experience with narratives developed for past climate change and related scenarios; and (3) the specific role of the SSPs in the current scenario framework as characterizing societal futures that have particular combinations of challenges to mitigation and adaptation.

The general purpose of narratives of societal development in climate change scenarios is to provide broad descriptions of future conditions that are relevant for both the analysis of emissions drivers and mitigation strategies, and the analysis of societal vulnerability to climate change, climate impacts and potential adaptation measures. To this end, narratives aim to convey a basic “storyline” that can guide the specification of further elements of the scenario, including quantitative elements such as population and economic growth patterns. A narrative of global development should also be able to guide regional and sectoral extensions of the scenarios, including the formulation of regional narratives that fit within the overall global picture. Finally, narratives should be sufficiently generic to allow useful coverage of the space of relevant futures by representing much broader categories of possible development pathways. This distinguishes narratives underlying climate change scenarios from much richer storylines that are sometimes used in decision-making contexts to illustrate the consequences of specific courses of action.

Previous narratives used in climate change scenarios conveyed the general nature of future development through key characteristics such as economic growth, regional integration, societal sustainability and environmental sustainability. These characteristics were also used to define sets of representative futures that cover a desired space of uncertainty for use in scenario analysis. Interestingly, the types of narratives (and their combinations into sets) employed in past scenarios exhibited similarities and recurrent themes (de Vries, 2005; Raskin et al., 2005; van Vuuren et al., 2012). This fact may point to the relevance of these themes to climate change analysis, but may also reflect a certain lock-in to a particular way of framing environmental scenario analysis.

As noted earlier, the current scenario framework calls for the SSPs, and therefore the narratives, to portray worlds that have varying challenges to mitigation and to adaptation. These challenges refer to characteristics of society, not to the amount of climate change or the stringency of the mitigation policy (factors that are not included in SSPs). Thus, the narratives were constructed from socioeconomic and environmental (but non-climate) elements judged to be important determinants of these challenges. While much is known about these determinants, there is still substantial uncertainty (O'Neill et al., 2014), particularly regarding determinants of the challenges to adaptation (Rothman et al., 2014; Schweizer and O'Neill, 2014).

Taken together, these considerations implied a method that iterated between desired characteristics of the full narratives and identification of specific narrative elements and assumptions (Fig. 2). Content for the SSPs was developed in a variety of approaches, essentially through expert judgment with a wide variety of experts from the IAM, IAV, development, futures studies, and vulnerability and risk research communities providing input through a series of dedicated meetings<sup>1</sup>. A first meeting resulted in the adoption of a set of incipient SSP narratives (O'Neill et al., 2012) that were further developed at a subsequent meeting through broader discussion of the drafts and initial quantifications of key

<sup>1</sup> For descriptions of the process, see Ebi et al. (2014), and [http://sedac.ipcc-data.org/ddc/ar5\\_scenario\\_process/parallel\\_nat\\_scen.html](http://sedac.ipcc-data.org/ddc/ar5_scenario_process/parallel_nat_scen.html). Much of this process was carried out under the auspices of the International Committee on New Integrated Climate change assessment Scenarios (ICONICS; <https://www2.cgd.ucar.edu/research/iconics>), which was formed to facilitate development and use of the new scenarios, including the SSPs and their quantitative and qualitative elements.



drivers. An author group (consisting of the authors of this paper) was formed to revise the narratives in light of feedback and to produce a paper documenting them and their production. As part of that process, draft narratives were posted for comment by the scientific community, and 38 pages of comments from 18 reviewers were collected and considered.

Lists of potential narrative elements considered to be important determinants of challenges to mitigation or adaptation were generated through expert discussions at the meetings described above, as well as through formal (Schweizer and O'Neill, 2014) and informal (Wilbanks and Ebi, 2014) expert elicitation. Ultimately, variables in six broad categories were considered to be important to represent in the SSPs: demographics, human development, economy and lifestyle, policies and institutions (excluding climate policies), technology, and environment and natural resources. This list is not meant to be exhaustive, but to provide sufficient guidance for developing basic narratives that – depending on future research needs – can be further adapted and extended. Principal determinants of challenges to mitigation, for example, include determinants of energy and land use, technological progress, and international policy institutions. In the case of challenges to adaptation, institutional factors, future inequality and poverty as well as possible attainment or failure in achieving different development objectives play a critical role.

The process of creating narratives from these elements was informed by pre-existing narratives from the IPCC Special Report on Emission Scenarios (Nakicenovic et al., 2000), the Millennium Ecosystem Assessment (Carpenter et al., 2005), and the UNEP Global Environment Outlook (GEO) scenarios (UNEP, 2002, 2007), among other global scenario exercises (van Vuuren et al., 2012). Possible illustrative starting points for SSP narratives were described in a number of papers (Kriegler et al., 2012; O'Neill et al., 2014; Schweizer and O'Neill, 2014), including analogies to SRES scenarios (Van Vuuren and Carter, 2014), and were considered by meeting participants and the narratives author group. Discussions among the author team and further development and revision of the narratives were informed also by work on the concept of challenges to adaptation (Rothman et al., 2014) and on the role of governance and political economy (Lane and Montgomery, 2014).

It was decided to develop five SSPs to span the challenges space, necessitating five different narratives (Fig. 1; O'Neill et al., 2014). Four of the narratives (SSP1, SSP3, SSP4, SSP5) describe the various combinations of high or low challenges to adaptation and mitigation, all of which were considered plausible enough to warrant SSP development. A fifth narrative (SSP2) described moderate challenges of both kinds and is intended to represent a future in which development trends are not extreme in either of the dimensions, but rather follow middle-of-the-road pathways relative to the span of plausible outcomes for each element. Most approaches to scenario design advocate an even number of scenarios to discourage use of a single scenario as a central case (Kok et al., 2006). However, this strategy has not always been successful, with scenario users sometimes selecting one scenario as either 'most likely' or 'closest to a model baseline'. This tendency convinced the SSP design group to explicitly provide a central pathway. The central case is not meant to be more likely than any of the other storylines or pathways. In fact, historical development of GHG emissions has often followed trajectories close to the upper bound of the range of earlier emissions scenarios, such as those from SRES (Nakicenovic et al., 2000). Including a central case was also intended to ensure that the pathways fill the challenges space and that the other four SSPs not drift toward the middle space, which might otherwise be perceived as not well covered.

### 3. Results: The basic SSP narratives

This section presents summaries of the five narratives developed to occupy each of the domains of the challenges space, along with some thoughts as to how the future societal development pathways they depict could plausibly emerge from current developments. Somewhat more discussion is provided for those SSPs, notably SSP4, which are less well represented in previous scenario exercises. More complete versions of all of the narratives are included in the Supporting Information. We employ the metaphor of a road or pathway in naming the SSPs in order to emphasize that they are intended to describe the evolution of global and regional development trends over time, rather than static snapshots of conditions at a particular point in time.

#### 3.1. SSP1: Sustainability—Taking the green road

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

SSP1, with its central features of commitment to achieving development goals, increasing environmental awareness in societies around the world, and a gradual move toward less resource-intensive lifestyles, constitutes a break with recent history in which emerging economies have followed the resource-intensive development model of industrialized countries. To some extent, elements of this scenario can already be found in the proliferation of "green growth" and "green economy" strategies in industrialized and developing countries (UNEP, 2011; UNESCAP, 2012), although their efficacy has been questioned (Bina and La Camera, 2011). As emphasized by Ocampo (2011), for these strategies to succeed there would need to be innovation in both industrialized and developing countries and adequate human and financial resources. Such innovation has been spurred by environmental policy (Ambec et al., 2013; Porter and van der Linde, 1995), and this SSP assumes that policy changes are driven by changing attitudes. The focus on equity, and the de-emphasis of economic growth as a

goal in and of itself in high-income countries, leads industrialized countries to support developing countries in their development goals, including green growth strategies, by providing access to human and financial resources and new technologies.

### 3.2. SSP2: Middle of the road

The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including improved living conditions and access to education, safe water, and health care. Technological development proceeds apace, but without fundamental breakthroughs. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Even though fossil fuel dependency decreases slowly, there is no reluctance to use unconventional fossil resources. Global population growth is moderate and levels off in the second half of the century as a consequence of completion of the demographic transition. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and to rapidly slow population growth. This growth, along with income inequality that persists or improves only slowly, continuing societal stratification, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes and constrain significant advances in sustainable development. These moderate development trends leave the world, on average, facing **moderate challenges to mitigation and adaptation**, but with significant heterogeneities across and within countries.

SSP2 does not imply a simple extrapolation of recent experience, but rather a development pathway that is consistent with typical patterns of historical experience observed over the past century. For example, emerging economies grow relatively quickly and then slow as incomes reach higher levels, the demographic transition occurs at average rates as societies develop, and technological progress continues without major slowdowns or accelerations. Thus it is a dynamic pathway, yet one in which future changes in various elements of the narrative are consistent with middle of the road expectations, rather than falling near the upper or lower bounds of possible outcomes. There are likely many reasons that trends in SSP elements could end up being moderate, and no specific stance is taken here as to motivating forces.

### 3.3. SSP3: Regional rivalry—A rocky road

A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns. Policies shift over time to become increasingly oriented toward national and regional security issues, including barriers to trade, particularly in the energy resource and agricultural markets. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development, and in several regions move toward more

authoritarian forms of government with highly regulated economies. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time, especially in developing countries. There are pockets of extreme poverty alongside pockets of moderate wealth, with many countries struggling to maintain living standards and provide access to safe water, improved sanitation, and health care for disadvantaged populations. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions. The combination of impeded development and limited environmental concern results in poor progress toward sustainability. Population growth is low in industrialized and high in developing countries. Growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change imply **high challenges to mitigation**. The limited progress on human development, slow income growth, and lack of effective institutions, especially those that can act across regions, implies **high challenges to adaptation** for many groups in all regions.

SSP3, with its theme of international fragmentation and a world characterized by regional rivalry can already be seen in some of the current regional rivalries and conflicts, but contrasts with globalization trends in other areas. It is based on the assumption that these globalization trends can be reversed by a number of events. For example, economic woes in major economies could spark increasing discontent with globalization and spur protectionist instincts. Alternatively, regional conflict over territorial or national issues could produce larger conflict between major countries, giving rise to increasing antagonism between and within regional blocs. Such a reversal of globalization trends due to regional conflict has happened before, for example on the eve of World War I (e.g. Ferguson, 2005). Regional rivalries reduce support for international institutions and development partners, thus weakening progress toward development goals, resulting in substantial changes to current trends in population growth, human health and well-being, and environmental protection in some low- and middle-income countries.

### 3.4. SSP4: Inequality—A road divided

Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Power becomes more concentrated in a relatively small political and business elite, even in democratic societies, while vulnerable groups have little representation in national and global institutions. Economic growth is moderate in industrialized and middle-income countries, while low income countries lag behind, in many cases struggling to provide adequate access to water, sanitation and health care for the poor. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. Uncertainty in the fossil fuel markets lead to underinvestment in new resources in many regions of the world. Energy companies hedge against price fluctuations partly through diversifying their energy sources, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources.

Environmental policies focus on local issues around middle and high income areas. The combination of some development of low carbon supply options and expertise, and a well-integrated international political and business class capable of acting quickly and decisively, implies **low challenges to mitigation**. **Challenges to adaptation are high** for the substantial proportions of populations at low levels of development and with limited access to effective institutions for coping with economic or environmental stresses.

SSP4, with its emphasis on both across- and within-country inequality, seems less well represented in previous scenario literature, and we discuss its assumptions in more detail here. Its central feature of rising inequality is assumed to arise from a number of factors discussed in the inequality literature, including skill-biased technology development (where technology replaces many low-skill jobs; Jaumotte et al., 2008; Lansing and Markiewicz, 2012) or capital returns (Piketty, 2014). Another key factor is the assumed generally low and highly unequal investments in education. Expanded education has been an important contributor to lowering inequality in the recent past (OECD, 2011; Cornia, 2012); this narrative assumes the converse, that limited access to education can increase inequality. In addition, less affluent groups are assumed to have weak political power, fewer economic opportunities, and limited access to credit (Vindigni, 2002; Bénabou, 2000), constraining both educational opportunities and income growth and making inequality more persistent. At the same time, those at the top end of the income scale (Atkinson et al., 2010; Roine et al., 2009) see their relative position reinforced through institutional changes that strengthen their bargaining power at the expense of low earners (Kumhof and Ranciere, 2010; Piketty et al., 2011). Across countries, the assumption that growth results in separation into different country income groups is consistent with the idea of “convergence clubs” (Galor, 1996; Quah, 1996a, 1996b) as opposed to the conditional convergence hypothesis (Barro and Sala-i-Martin, 2003).

There is very mixed evidence on the current inequality trends within and across countries. Wage inequality across countries has generally been increasing since 1980 in both OECD and non-OECD countries (Galbraith, 2011). While a simple population-weighted measure of international income dispersion is falling, this is almost entirely due to China, and except in the very recent past, the measure has been rising when China is excluded (Milanovic, 2012). Historical experience regarding within-country inequality is mixed, while SSP4 assumes that it increases in the long term. For some countries this means that recent trends will eventually reverse. This is plausible because such improvements can be temporary. For example, falling inequality within Latin America appears to be largely due to expanded education and reforms introduced by leftist governments (Cornia, 2012). SSP4 assumes increasingly restricted access to education, which could plausibly halt or reverse improvements. In addition, (Galbraith, 2011) notes that downturns in inequality from populist governments rarely endure.

It is also important to note that this pathway envisions a slow down, but not a halt to or reversal of the growth of the global middle class. Kharas (2010) defines the global middle class as consisting of people with daily expenditure between \$10 and \$100. He estimates that there are 1.8 billion people in the global middle class in 2009 (~25% of the global population), and that this total could rise to 4.8 billion (~60%) in 2030, due almost entirely to East Asia. The SSP4 narrative assumes that growth is substantially smaller than it is in this outlook, but does not assume that it is halted entirely.

Finally, the assumptions that inequality and a perception of scarce energy resources lead to a decline in social cohesion and

increased potential for conflict are consistent with scholarship in these areas. Empirically, there is a significant negative relationship between inequality and social cohesion across a variety of measures (trust, solidarity, dysfunction; Uslaner, 2002; Bjørnskov, 2008; Wilkinson and Pickett, 2009; Kemp-Benedict, 2011; Paskov and Dewilde, 2012). Similarly, there is historical precedent for conflict over energy resources in consuming countries (England, 1994) and in producing countries (Ross, 2004), with potential for intensification if resources are further constrained (Lee, 2005).

### 3.5. SSP5: Fossil-fueled development—Taking the highway

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

SSP5 foresees accelerated globalization and rapid development of developing countries, including a significant improvement of institutions and the economic participation of disadvantaged population groups. Such trends have little historic precedent, particularly on the global scale. Only a limited number of nations have managed the transition to a market economy with effective institutions (Lane and Montgomery, 2014), and the long-term prospects of currently rapidly developing economies such as China, India and Brazil remain uncertain. However, two historically unprecedented developments in the recent past suggest a break from past trends. First, the economic success of emerging economies and more recently least developed countries has given rise to an emergent global middle class that has been lacking in most regions of the world (Kharas, 2010). The new middle class could stabilize global economic development by promoting robust growth in demand for services and goods. It may also generate societal pressure toward improved institutions and more participatory societies as for example has been observed in Brazil. Second, the digital revolution enables a global discourse of a significant and increasing fraction of the global population for the first time in human history which may lead to a rapid rise in global institutions



and promote the ability for global coordination (Keohane and Nye, 2000).

#### 4. The SSP narratives: Relationships to each other and to existing narratives

As important as the individual narratives are in and of themselves, we need to also consider them as a set. Are they sufficiently distinct in their socioeconomic challenges to mitigation and adaptation to meet the needs specified in the conceptual framework? Do they span a wide range of development outcomes? And how do they relate to other existing global scenario narratives?

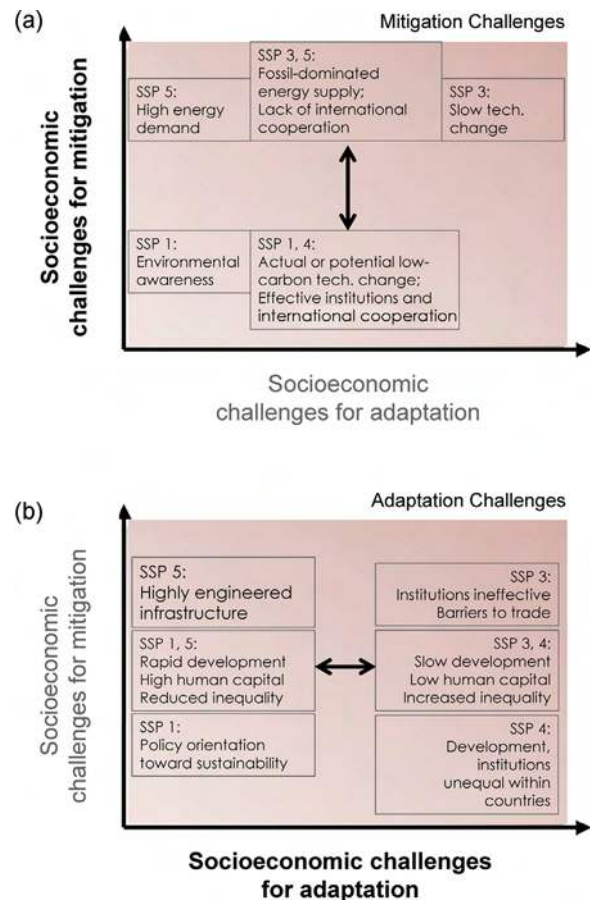
Regarding the needs of the conceptual framework, the SSP narratives aim to capture the combinations of challenges to mitigation and adaptation illustrated in Fig. 1. SSP1 leads to low challenges to both mitigation and adaptation due to a combination of substantial income growth, a reduction in inequality, strong institutions, and a sustained value shift over time that prioritizes sustainable development. As discussed above, SSP2 is a scenario in which elements follow middle-of-the-road trends, leading to intermediate challenges to both mitigation and adaptation. In contrast, SSP3 leads to high challenges to both mitigation and adaptation resulting from slow growth in income and slow technological change, ineffective institutions, and low investment in human capital.

SSPs 4 and 5 are mixed scenarios in which a particular set of challenges dominates. SSP4 is a world in which it may not be too difficult to mitigate climate change, but would be quite difficult to adapt to it. A central feature of this pathway is growing inequality both across and within countries, including in the currently industrialized world. Mitigation challenges are relatively low due to modest economic growth combined with availability of technologies and expertise within the portion of the economy in which power is concentrated, while adaptation challenges are high for the substantial portion of the population with relatively low income education and little access to effective institutions. In SSP5, economic growth is very high, enabling many development goals to be achieved within short time frames, so that challenges to adaptation are relatively low. However energy demand grows rapidly and the energy system continues to rely heavily on fossil fuels, leading to high challenges to mitigation.

Fig. 3 summarizes the pathway elements that lead to the particular combinations of challenges represented by each SSP. For example, high challenges to mitigation are hypothesized to be driven in these narratives by fossil-dominated energy supply either globally or regionally, along with a lack of capacity (or desire) for international cooperation on global environmental issues. These challenges are exacerbated in SSP5 by very high energy demand and in SSP3 by slow technological change. In contrast, low challenges to mitigation are driven by development of low-carbon energy technologies (or the capacity for that development) and effective means of cooperating on international policy. These challenges are further reduced in SSP1 by a general orientation toward environmental sustainability.

High challenges to adaptation are assumed to be driven by a combination of slow development, low investments in human capital, and increased inequality. These challenges are exacerbated in SSP3 by ineffective institutions and barriers to trade, and in SSP4 by high inequality within (as well as across) countries. In contrast, low challenges to adaptation are driven by rapid development and formation of human capital and reduced inequality, further reduced in SSP5 by highly engineered infrastructure and in SSP1 by an orientation toward environmental sustainability.

Regarding the range of development pathways the SSPs describe, Tables 1–3 summarize assumptions about key elements of the narratives. The tables show that the SSPs span a wide



**Fig. 3.** A summary of SSP elements that contribute to high or low challenges to mitigation (a) and adaptation (b). Elements listed toward the top or bottom of the challenges space in figure (a) apply to pathways with high or low challenges to mitigation, respectively, while elements listed toward the left or right side of the challenges space in figure (b) apply to pathways with low or high challenges to adaptation, respectively.

range of assumptions about individual elements of the pathways. Demographic trends vary widely. For example, SSPs 1 and 5 experience low population growth paths at the global level driven in part by rapid improvements in education, fast income growth, and rapid urbanization, leading to relatively rapid declines in fertility in high fertility countries. In contrast, SSPs 3 and 4 experience high population growth rates, a consequence of much slower improvements in education and income in high fertility countries. In countries where fertility is already low, there is no single widely accepted theory of the determinants of future fertility change (Basten et al., 2014). Therefore, demographic trends in these countries are not chosen primarily by appealing to existing theory, but rather to either contribute to the challenges each SSP is intended to present or increase the range of demographic outcomes achieved across the full set of SSPs. For example, the combination of low fertility and migration in SSP3 would produce a very old age structure in the industrialized world, which could make it more difficult to cope with some types of climate change impacts. SSP5 assumes high net immigration and fertility above replacement level in the high-income countries in order to provide one pathway in which industrialized country population growth is more substantial.

Economic development is rapid and broad-based in SSPs 1 and 5, which gives rise to substantial reductions in inequality, both between and within countries, and is accompanied by continued globalization and international trade. SSP 1 differs in that there is a

**Table 1**

Summary of assumptions regarding demographic and human development elements of SSPs. See [KC and Lutz \(2014\)](#) for the definitions of country fertility groupings for demographic elements. Country groupings referred to in table entries for human development are based on the World Bank definition of low-income (LIC), medium-income (MIC) and high-income (HIC) countries.

SSP element	SSP1			SSP2			SSP3			SSP4			SSP5			
	Country fertility groupings for demographic elements															
	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	
Demographics																
Population																
Growth	Relatively low			Medium			High		Low	Relatively high		Low	Relatively low			
Fertility	Low	Low	Med	Medium			High	High	Low	High	Low	Low	Low	Low	High	
Mortality	Low			Medium			High			High	Med	Med	Low			
Migration	Medium			Medium												High
Urbanization																
Level	High			Medium			Low			High	High	Med	High			
Type	Well managed			Continuation of historical patterns			Poorly managed			Mixed across and within cities			Better mgmt. over time, some sprawl			
Human development																
Education	High			Medium			Low			V.low/uneq.	Low/uneq.	Med/uneq.	High			
Health investments	High			Medium			Low			Unequal within regions, lower in LICs, medium in HICs			High			
Access to health facilities, water, sanitation	High			Medium			Low			Unequal within regions, lower in LICs, medium in HICs			High			
Gender equality	High			Medium			Low			Unequal within regions, lower in LICs, medium in HICs			High			
Equity	High			Medium			Low			Medium			High			
Social cohesion	High			Medium			Low			Low, stratified			High			
Societal participation	High			Medium			Low			Low			High			

pronounced value shift, resulting in somewhat less rapid economic growth as compared to SSP5, but compensated by other factors such as better environmental quality and higher level of equity. Accounting for better livelihoods, the environment, equity as well as other factors, overall welfare is higher in SSP1 as compared to SSP5. In contrast economic growth is slow and inequality is compounded in SSPs 3 and 4, with inequality within countries especially high in SSP4. SSP3 also envisions substantial obstacles to

global trade, with implications for development as well as for challenges to adaptation.

Regarding the relationships of the SSP narratives to those in previous scenario sets, previous scenarios were commonly grouped according to assumptions they made about key driving forces rather than according to outcomes of the narratives such as their implied challenges to mitigation and adaptation. The SRES scenarios, for example, are typically described as spanning a space

**Table 2**

Summary of assumptions regarding Economy & Lifestyle and Policies & Institutions elements of SSPs. Country groupings referred to in table entries are based on the World Bank definition of low-income (LIC), medium-income (MIC) and high-income (HIC) countries.

SSP element	SSP1	SSP2	SSP3	SSP4	SSP5
<b>Economy &amp; lifestyle</b>					
Growth (per capita)	High in LICs, MICs; medium in HICs	Medium, uneven	Slow	Low in LICs, medium in other countries	High
Inequality	Reduced across and within countries	Uneven moderate reductions across and within countries	High, especially across countries	High, especially within countries	Strongly reduced, especially across countries
International trade	Moderate	Moderate	Strongly constrained	Moderate	High, with regional specialization in production
Globalization	Connected markets, regional production	Semi-open globalized economy	De-globalizing, regional security	Globally connected elites	Strongly globalized, increasingly connected
Consumption & Diet	Low growth in material consumption, low-meat diets, first in HICs	Material-intensive consumption, medium meat consumption	Material-intensive consumption	Elites: high consumption lifestyles; Rest: low consumption, low mobility	Materialism, status consumption, tourism, mobility, meat-rich diets
<b>Policies &amp; institutions</b>					
International Cooperation	Effective	Relatively weak	Weak, uneven	Effective for globally connected economy, not for vulnerable populations	Effective in pursuit of development goals, more limited for envt. goals
Environmental Policy	Improved management of local and global issues; tighter regulation of pollutants	Concern for local pollutants but only moderate success in implementation	Low priority for environmental issues	Focus on local environment in MICs, HICs; little attention to vulnerable areas or global issues	Focus on local environment with obvious benefits to well-being, little concern with global problems
Policy orientation	Toward sustainable development	Weak focus on sustainability	Oriented toward security	Toward the benefit of the political and business elite	Toward development, free markets, human capital
Institutions	Effective at national and international levels	Uneven, modest effectiveness	Weak global institutions/ natl. govts. dominate societal decision-making	Effective for political and business elite, not for rest of society	Increasingly effective, oriented toward fostering competitive markets



**Table 3**

Summary of assumptions regarding Technology and Environment & Natural Resources elements of SSPs. Country groupings referred to in table entries are based on the World Bank definition of low-income (LIC), medium-income (MIC) and high-income (HIC) countries.

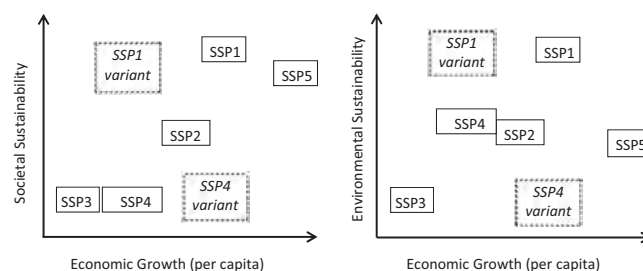
SSP element	SSP1	SSP2	SSP3	SSP4	SSP5
<b>Technology</b>					
Development	Rapid	Medium, uneven	Slow	Rapid in high-tech economies and sectors; slow in others	Rapid
Transfer	Rapid	Slow	Slow	Little transfer within countries to poorer populations	Rapid
Energy tech change	Directed away from fossil fuels, toward efficiency and renewables	Some investment in renewables but continued reliance on fossil fuels	Slow tech change, directed toward domestic energy sources	Diversified investments including efficiency and low-carbon sources	Directed toward fossil fuels; alternative sources not actively pursued
Carbon intensity	Low	Medium	High in regions with large domestic fossil fuel resources	Low/medium	High
Energy intensity	Low	Uneven, higher in LICs	High	Low/medium	High
<b>Environment &amp; natural resources</b>					
Fossil constraints	Preferences shift away from fossil fuels	No reluctance to use unconventional resources	Unconventional resources for domestic supply	Anticipation of constraints drives up prices with high volatility	None
Environment	Improving conditions over time	Continued degradation	Serious degradation	Highly managed and improved near high/middle-income living areas, degraded otherwise	Highly engineered approaches, successful management of local issues
Land Use	Strong regulations to avoid environmental tradeoffs	Medium regulations lead to slow decline in the rate of deforestation	Hardly any regulation; continued deforestation due to competition over land and rapid expansion of agriculture	Highly regulated in MICs, HICs; largely unmanaged in LICs leading to tropical deforestation	Medium regulations lead to slow decline in the rate of deforestation
Agriculture	Improvements in ag productivity; rapid diffusion of best practices	Medium pace of tech change in ag sector; entry barriers to ag markets reduced slowly	Low technology development, restricted trade	Ag productivity high for large scale industrial farming, low for small-scale farming	Highly managed, resource-intensive; rapid increase in productivity

defined by their degree of economic vs environmental orientation, and their regional vs global orientation (Nakicenovic et al., 2000). The two approaches to developing or describing narratives are not mutually exclusive. The SSPs can be mapped not only to the challenges space in Fig. 1, but also to spaces defined by assumptions about key input elements. For example, it is possible to map the SSPs to the space defined for the SRES scenarios. The relatively optimistic SSP1 that is oriented toward sustainability, and relatively pessimistic SSP3 in which geopolitical regions fragment rather than globalize, share features with SRES B1 and A2 worlds, respectively (Kriegler et al., 2012; O'Neill et al., 2014; van Vuuren and Carter, 2014). Similarly, SSP5 – a high economic growth pathway with a fossil-based energy system – shares features of the SRES A1F scenario (Kriegler et al., 2012; O'Neill et al., 2014; van Vuuren and Carter, 2014). There are also relationships with the storylines of other assessments (see for example Table 1 of van Vuuren and Carter, 2014). The Millennium Ecosystem Assessment (MA) scenarios (Carpenter et al., 2005) are interesting in this respect given their ample attention to narratives. For example, the MA Order from Strength scenario provides insight into possible consequences of an SSP4-type world (van Vuuren and Carter, 2014), while the MA Technogarden scenario shares features with SSP1.

In summary, existing sets of narratives were often characterized in terms of economic growth, regional integration, societal sustainability (equity and governance) and environmental sustainability (environmental awareness and lifestyles). The SSPs can also be mapped to spaces defined by assumptions about these elements. As illustrated in Fig. 4, such mappings indicate that the SSPs not only cover the range of challenges to mitigation and adaptation, but also to a large extent the space of low vs. high economic growth, low vs. high societal sustainability and low vs.

high environmental sustainability seen in other scenario sets. Exceptions are the case of low economic growth combined with high societal and environmental sustainability, and the case of medium to high economic growth coupled with low societal and environmental sustainability. The first case (low growth, high societal and environmental sustainability) would require an SSP1 variant with a more dramatic shift to lower consumption lifestyles, sharing some features with existing scenarios such as the Great Transition (Raskin et al., 2002) and Sustainability First (Rothman et al., 2007). The second case (high growth, low societal and environmental sustainability) could be captured in a variant of SSP4 in which an internationally well-connected society has very limited environmental awareness and exposure.

The discussion shows that there exists a close link between socio-economic challenges to mitigation and adaptation, and the dimensions of sustainability and development. As a result, the SSPs also cover a wide range of development and sustainability



**Fig. 4.** Illustrative mapping of SSPs to a space defined by elements of the SSP narratives as opposed to consequences of the narratives for challenges to mitigation and adaptation.

outcomes (see Fig. 4). Thus, they can also be a useful tool for the analysis of broader sustainable development objectives.

## 5. Discussion and conclusions

There are several open questions about the design and use of SSPs. First, a broad question remains as to the effectiveness of pathways characterized by a global sense of the challenges to mitigation or adaptation they present. If, for example, challenges to adaptation are dominated by local considerations, and if many of these considerations have only weak connections to development trends in other regions or at a larger scale, then a global starting point for scenario development would seem to be a less effective approach. We believe that an initial global framing can in fact be useful, partly because local challenges will depend to some degree on factors at the regional, national, or international level (e.g., energy prices, trade possibilities, international institutions, global competition, technology spill-overs, policies, etc.), and partly because a global framing serves as a means of deciding which local assumptions to make, even in those cases in which there are only weak connections to larger-scale factors (for example, local assumptions might be made to reflect the same type and degree of challenges that are the intention of the global pathway). However, it will be important for the lessons learned in carrying out studies in more specific contexts to be communicated to and incorporated in any revision process for global scale narrative development.

Second, it was already clear in the narrative design process that more than one type of narrative could be located within a particular domain of the challenges space. Which type might be most useful, or whether the development of more than one type per domain would be useful, remains to be seen. For example, as discussed in Section 4, an alternative SSP1 storyline could be envisioned that involves a substantially larger shift in values toward lower consumption lifestyles, leading to a version of the narrative with much lower economic growth and energy demand. Similarly, an alternative version of SSP2 could be developed in which challenges to mitigation and adaptation were moderate on average across regions, but varied widely from region to region, rather than being more uniformly middle-of-the-road as assumed in the SSP2 narrative presented here. These regional differences could arise from, for example, current trends in water security without considering any potential impacts of climate change (which are outside the SSPs). The storylines presented in this paper are canonical, but the canon is not exclusive. To make a broadly useful framework for climate scenario development, it will benefit the research community if alternative storylines that can be located within a particular domain of the challenges space are explicitly identified as such.

Third, it may also be useful to consider narratives describing development pathways that move through more than one domain of the challenges space over time. The approach taken by the narratives presented here is to describe development pathways that move from current conditions toward futures in which the challenges to mitigation and adaptation are progressively more and more consistent with the intended outcome for the SSP. However it is possible that a development pathway could move toward one combination of challenges before changing direction and moving toward another. For example, surprises may drive such a change. In a world developing along the pessimistic SSP3 narrative, a surprise breakthrough in mitigation technology may quickly lower the challenges to mitigation and move society into the SSP4 domain. Exploring development pathways that move through more than one domain may be an especially effective way to consider how fast societal trends may change, whether path dependency may limit the long-term futures that could

follow from trends over the next few decades, and ultimately how these factors may influence challenges to mitigation and adaptation.

In addition to these open questions, it is also important to keep in mind that the narratives presented here are qualitative components of basic SSPs. Extensions to these narratives will in many cases be required to support more detailed analyses of climate response options and impacts in particular sectors or locations (van Ruijven et al., 2014) and risk and vulnerability assessments at different scales. Examples of extensions are already beginning to appear. In order to produce the SSP-based integrated assessment model scenarios that appear in this special issue, SSPs had to be extended to provide more detailed assumptions about future energy systems and land use in order to specify required inputs to IAMs. Ebi (2014) has elaborated on the public health-related aspects of the narratives, and Birkmann et al. (2013) elaborated on the risk and vulnerability aspects in the context of climate change and natural hazards. In addition, extensions known as “representative agricultural pathways” to support agricultural impact assessment are under development for the Agricultural Model Intercomparison and Improvement Project (AgMIP). Moreover, extensions with respect to the pollution and health dimension of the SSPs are discussed in several other places.

Capturing lessons from experience gained in applying the SSPs to integrated climate change research, as well as in extending them to particular sectors and geographic scales, should be a high priority. In that way future revisions of the narratives, or the development of additional narratives, will most effectively support integrated climate change research.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2015.01.004.

## References

- Alcamo, J., 2001. *Scenarios as Tools for International Environmental Assessments*. European Environment Agency, Copenhagen.
- Ambec, S., Cohen, M.A., Elgie, S., Lanoie, P., 2013. The porter hypothesis at 20: can environmental regulation enhance innovation and competitiveness? *Rev. Environ. Econ. Policy* 7, 2–22. <http://dx.doi.org/10.1093/reep/res016>.
- Ash, N., Blanco, H., Brown, C., Garcia, K., Tomich, T., Vira, B., 2010. *Ecosystems and Human Well-Being: A Manual for Assessment Practitioners*. Island Press, Washington, DC.
- Atkinson, A.B., Piketty, T., Saez, E., 2010. *Top Incomes in the Long Run of History*. Institute for Research on Labor and Employment, Berkeley, CA.
- Barro, R.J., Sala-i-Martin, X., 2003. *Economic Growth*, second ed. The MIT Press, Cambridge, MA, US.
- Basten, S., Sobotka, T., Zeman, K., 2014. Future fertility in low fertility countries. In: Lutz, W., Butz, W.P.K.S. (Eds.), *World Population & Human Capital in the Twenty-First Century*. Oxford University Press, Oxford, UK, pp. 39–146.
- Bénabou, R., 2000. Unequal societies: income distribution and the social contract. *Am. Econ. Rev.* 90, 96–129.
- Bina, O., La Camera, F., 2011. Promise and shortcomings of a green turn in recent policy responses to the double crisis. *Ecol. Econ.* 70, 2308–2316. <http://dx.doi.org/10.1016/j.ecolecon.2011.06.021>.
- Birkmann, J., Cutter, S., Rothman, D., Welle, T., Garschagen, M., Van Ruijven, B., O'Neill, B., Preston, B., Kienberger, S., Cardona, O.D., Siagian, T., Hidayati, D., Setiadi, N., Binder, C., Hughes, B., Pulwarty, R., 2013. Scenarios for vulnerability—opportunities and constraints in the context of climate change and disaster risk. *Clim. Change*. <http://dx.doi.org/10.1007/s10584-013-0913-2> (online first).
- Björnskov, C., 2008. Social trust and fractionalization: a possible reinterpretation. *Eur. Sociol. Rev.* 24, 271–283. <http://dx.doi.org/10.1093/esr/jcn004>.
- Carpenter, S.R., Pingali, P.L., Bennett, E.M., Zurek, M.B. (Eds.), 2005. *Ecosystems and Human Well-Being: Scenarios*. Findings of the Scenarios Working Group of the Millennium Ecosystem Assessment. Island Press, Washington, DC.
- Cornia, G.A., 2012. *Inequality Trends and their Determinants: Latin America Over 1990–2010*. Working Papers Series No. wp2012\_02.rtf, Università degli Studi di Firenze, Dipartimento di Scienze Economiche.
- Crespo Cuaresma, J., 2014. Income projections for climate change research: a framework based on human capital dynamics. *Global Environ. Change* (this special issue, submitted).

- de Vries, B., 2005. Dealing with uncertainty and complexity: the contribution of scenarios. In: *Integrated History and future of People on Earth (IHOPE)*, 96th Dahlem Workshop. Universität Berlin, Berlin, Germany.
- Dellink, R., Chateau, J., Lanzi, E., Magné, B., 2014. Long-term economic growth projections in the shared socioeconomic pathways. *Global Environ. Change* (this special issue, accepted).
- Ebi, K.L., 2014. Health in the new scenarios for climate change research. *Int. J. Environ. Res. Public. Health* 11, 30–46. <http://dx.doi.org/10.3390/ijerph110100030>.
- Ebi, K.L., Hallegatte, S., Kram, T., Arnell, N.W., Carter, T.R., Edmonds, J.A., Kriegler, E., Mathur, R., O'Neill, B.C., Riahi, K., Winkler, H., Van Vuuren, D.P., Zwickel, T., 2014. A new scenario framework for climate change research: background, process, and future directions. *Clim. Change*, <http://dx.doi.org/10.1007/s10584-013-0912-3>.
- England, R.W., 1994. Three reasons for investing now in fossil fuel conservation: technological lock-in, institutional inertia, and oil wars. *J. Econ. Issues* 28, 755–776.
- Ferguson, N., 2005. Sinking globalization. *Foreign Aff.* 84 (2), 64–77.
- Galbraith, J.K., 2011. Inequality and economic and political change: a comparative perspective. *Cambridge J. Regions Econ. Soc.* 4, 13–27.
- Galor, O., 1996. Convergence? Inferences from theoretical models. *Econ. J.* 106, 1056–1069. <http://dx.doi.org/10.2307/2235378>.
- Groves, D.G., Lempert, R.J., 2007. A new analytic method for finding policy-relevant scenarios. *Global Environ. Change* 17 (1), 73–85.
- Jaumotte, F., Lall, S., Papageorgiou, C., 2008. Rising income inequality: technology, or trade and financial globalization? In: *IMF Working Paper*. International Monetary Fund, Washington, DC, pp. 36.
- Jiang, L., O'Neill, B., 2014. Urbanization projections for the shared socioeconomic pathways. *Global Environ. Change* (this special issue).
- Jones, R.N., Patwardhan, A., Cohen, S., Dessai, S., Lammel, A., Lempert, R., Mirza, M.Q., von Storch, H., 2014. Foundations for decision making. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- KC, S., Lutz, W., 2014. The human core of the shared socioeconomic pathways: population scenarios by age, sex and level of education for all countries to 2100. *Global Environ. Change*, in press. <http://dx.doi.org/10.1016/j.gloenvcha.2014.06.004>.
- Kemp-Benedict, E., 2011. Political regimes and income inequality. *Econ. Lett.* 113, 266–268. <http://dx.doi.org/10.1016/j.econlet.2011.08.002>.
- Keohane, R.O., Nye Jr., J.S., 2000. Globalization: What's new? What's not? (And so what?). *Foreign Policy* 118, 104–119.
- Kharas, H., 2010. The Emerging Middle Class in Developing Countries. OECD Development Centre, Paris, France.
- Kok, K., Rothman, D.S., Patel, M., 2006. Multi-scale narratives from an IA perspective: Part I. European and Mediterranean scenario development. *Futures* 38 (3), 261–284.
- Kriegler, E., Edmonds, J., Hallegatte, S., Ebi, K.L., Kram, T., Riahi, K., Winkler, H., van Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared climate policy assumptions. *Clim. Change* 122, 401–414. <http://dx.doi.org/10.1007/s10584-013-0971-5>.
- Kriegler, E., O'Neill, B.C., Hallegatte, S., Kram, T., Lempert, R.J., Moss, R.H., Wilbanks, T., 2012. The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. *Global Environ. Change* 22, 807–822. <http://dx.doi.org/10.1016/j.gloenvcha.2012.05.005>.
- Kumhof, M., Ranciere, R., 2010. Inequality, Leverage and Crises. International Monetary Fund, Washington, DC.
- Lane, L., Montgomery, W.D., 2014. An institutional critique of new climate scenarios. *Clim. Change* 122, 447–458. <http://dx.doi.org/10.1007/s10584-013-0919-9>.
- Lansing, K.J., Markiewicz, A., 2012. In: Sinn, H.-W., Stimmelmayer, M. (Eds.), *Top Incomes, Rising Inequality, and Welfare*. CESifo Working Paper Series, CESifo, Munich, Germany.
- Lee, P.K., 2005. China's quest for oil security: oil (wars) in the pipeline? *Pacific Rev.* 18, 265–301.
- Leggett, J., Pepper, W.J., Swart, R.J., 1992. Emissions scenarios for IPCC: An update. In: Houghton, J.T., Callander, B.A., Varney, S.K. (Eds.), *Climate Change 1992. Supplementary Report to the IPCC Scientific Assessment*. Cambridge University Press, Cambridge, pp. 69–95.
- Leimbach, M., Kriegler, E., Roming, N., Schwanitz, J., 2014. Future growth patterns of world regions—a GDP scenario approach. *Global Environ. Change* (this special issue, submitted).
- Lempert, R., Nakicenovic, N., Sarewitz, D., Schlesinger, M., 2004. Characterizing climate-change uncertainties for decision-makers. *Clim. Change* 65, 1–9.
- Milanovic, B., 2012. Global inequality recalculated and updated: the effect of new PPP estimates on global inequality and 2005 estimates. *J. Econ. Inequality* 10, 1–18.
- Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J., 2010. The next generation of scenarios for climate change research and assessment. *Nature* 463, 747–756. <http://dx.doi.org/10.1038/nature08823>.
- Nakicenovic, N., Alcamo, J., Davies, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., Lebre, E., Rovere, L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H.H., Sankovski, A., Schelsinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N., Dadi, Z., 2000. *Special Report on Emissions Scenarios*. Cambridge University Press, Cambridge.
- O'Neill, B., Carter, T.R., Ebi, K.L., Edmonds, J., Hallegatte, S., Kemp-Benedict, E., Kriegler, E., Mearns, L., Moss, R., Riahi, K., van Ruijven, B., van Vuuren, D., 2012. *Meeting Report of the Workshop on the Nature and Use of New Socio-economic Pathways for Climate Change Research*. November 2–4, 2011, Boulder, CO. National Center for Atmospheric Research (NCAR), Boulder, CO, USA. Available at: <https://www2.cgd.ucar.edu/sites/default/files/iconics/Boulder-Workshop-Report.pdf>.
- O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Clim. Change* 122, 387–400. <http://dx.doi.org/10.1007/s10584-013-0905-2>.
- Ocampo, J.A., 2011. The macroeconomics of the green economy. In: *The Transition to a Green Economy: Benefits, Challenges and Risks from a Sustainable Development Perspective*. United Nations Division for Sustainable Development, New York, NY, USA, pp. 16–39.
- OECD, 2011. An overview of growing income inequalities in OECD countries: main findings. In: *Divided We Stand: Why Inequality Keeps Rising*. Organization for Economic Co-operation and Development, Paris, France, pp. 21–46.
- Paskov, M., Dewilde, C., 2012. Income inequality and solidarity in Europe. *Res. Soc. Stratif. Mobility* 30, 415–432.
- Piketty, T., 2014. *Capital in the Twenty-First Century*. Harvard University Press, Cambridge, MA.
- Piketty, T., Saez, E., Stantcheva, S., 2011. Optimal Taxation of Top Labor Incomes: A Tale of Three Elasticities. In: *Working Paper 17616*. National Bureau of Economic Research. <http://www.nber.org/papers/w17616>.
- Porter, M.E., van der Linde, C., 1995. Toward a new conception of the environment-competitiveness relationship. *J. Econ. Perspect.* 9, 97–118.
- Quah, D.T., 1996a. Empirics for economic growth and convergence. *Europ. Econ. Rev.* 40, 1353–1375.
- Quah, D.T., 1996b. Twin peaks: growth and convergence in models of distribution dynamics. *Econ. J.* 106, 1045–1055.
- Raskin, P., Banuri, T., Gallopin, G., Gutman, P., Hammond, A., Kates, R., Swart, R., 2002. *Great Transition: The Promise and Lure of the Times Ahead*. Global Scenario Group, Stockholm Environment Institute, Boston, MA.
- Raskin, P., Monks, F., Ribeiro, T., van Vuuren, D., Zurek, M., 2005. Global scenarios in historical perspective. In: Carpenter, S.R., et al. (Eds.), *Ecosystems and Human Well-Being: Scenarios: Findings of the Scenarios Working Group*. Island Press, Washington, DC, pp. 35–44.
- Roine, J., Vlachos, J., Waldenström, D., 2009. The long-run determinants of inequality: what can we learn from top income data? *J. Public Econ.* 93, 974–988.
- Ross, M.L., 2004. What do we know about natural resources and civil war? *J. Peace Res.* 41, 337–356.
- Rothman, D.S., Romero-Lankao, P., Schweizer, V.J., Bee, B.A., 2014. Challenges to adaptation: a fundamental concept for the shared socio-economic pathways and beyond. *Clim. Chang* 122, 495–507. <http://dx.doi.org/10.1007/s10584-013-0907-0>.
- Rothman, Dale S., Agard, J., Alcamo, J. (Eds.), 2007. *The Future Today, in United Nations Environment Programme, in Global Environment Outlook 4*. UNEP, Nairobi, pp. 397–454.
- Schweizer, V.J., O'Neill, B.C., 2014. Systematic construction of global socioeconomic pathways using internally consistent element combinations. *Clim. Change* 122, 431–445. <http://dx.doi.org/10.1007/s10584-013-0908-z>.
- Taylor, K.E., Stouffer, R.J., Meehl, G.A., 2012. A summary of the CMIP5 experiment design. *Bull. Am. Meteorol. Soc.* 93, 485–498.
- UNEP, 2002. *Global Environment Outlook 3*. United Nations Environment Programme, London.
- UNEP, 2007. *Global Environment Outlook 4: Environment for Development*. United Nations Environment Program, Nairobi.
- UNEP, 2011. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*. United Nations Environment Programme, Nairobi, Kenya.
- UNESCAP, 2012. *Low Carbon Green Growth Roadmap for Asia and the Pacific: Turning Resource Constraints and the Climate Crisis into Economic Growth Opportunities*. United Nations Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand.
- Uslaner, E.M., 2002. *The Moral Foundations of Trust*. Cambridge University Press, Cambridge.
- Van Ruijven, B., Levy, M.A., Agrawal, A., Biermann, F., Birkmann, J., Carter, T.R., Ebi, K.L., Garschagen, M., Jones, B., Jones, R., Kemp-Benedict, E., Kok, M., Kok, K., Lemos, M.C., Lucas, P.L., Orlove, B., Pachauri, S., Parris, T.M., Patwardhan, A., Petersen, A., Preston, B.L., Ribot, J., Rothman, D.S., Schweizer, V.J., 2014. Enhancing the relevance of shared socioeconomic pathways for climate change impacts, adaptation and vulnerability research. *Clim. Change* 122, 481–494. <http://dx.doi.org/10.1007/s10584-013-0931-0>.
- Van Vuuren, D.P., Carter, T.R., 2014. Climate and socio-economic scenarios for climate change research and assessment: reconciling the new with the old. *Clim. Change* 122, 415–429. <http://dx.doi.org/10.1007/s10584-013-0974-2>.
- Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M.,



- Nakicenovic, N., Smith, S.J., Rose, S.K., 2011. The representative concentration pathways: an overview. *Clim. Change* 109, 5–31, <http://dx.doi.org/10.1007/s10584-011-0148-z>.
- van Vuuren, D.P., Kok, M.T.J., Girod, B., Lucas, P.L., de Vries, B., 2012. Scenarios in global environmental assessments: key characteristics and lessons for future use. *Global Environ. Change* 22 (4), 884–895.
- Van Vuuren, D.P., Kriegler, E., O'Neill, B.C., Ebi, K.L., Riahi, K., Carter, T.R., Edmonds, J., Hallegatte, S., Kram, T., Mathur, R., Winkler, H., 2014. A new scenario framework for climate change research: scenario matrix architecture. *Clim. Change* 122, 373–386, <http://dx.doi.org/10.1007/s10584-013-0906-1>.
- Vergragt, P.J., Quist, J., 2011. Backcasting for sustainability: introduction to the special issue. *Technological forecasting and social change*.
- Backcasting Sustainability 78 (5), 747–755, <http://dx.doi.org/10.1016/j.techfore.2011.03.010>.
- Vindigni, A., 2002. *Income Distribution and Skilled Biased Technological Change*. Working Papers (Princeton University. Industrial Relations Section), Princeton University, Princeton, NJ.
- Webster, M.D., Forest, C., Reilly, J.M., Babiker, M., Kickligher, D., Mayer, M., Prinn, R., Sarofim, M.C., Sokolov, A., Stone, P., Wang, C., 2003. *Uncertainty analysis of climate change and policy response*. *Clim. Change* 61, 295–320.
- Wilbanks, T.J., Ebi, K.L., 2014. SSPs from an impact and adaptation perspective. *Clim. Change* 122, 473–479, <http://dx.doi.org/10.1007/s10584-013-0903-4>.
- Wilkinson, R.G., Pickett, K.E., 2009. *Income inequality and social dysfunction*. *Annu. Rev. Sociol.* 35, 493–511.

## Appendix (i.e. Supporting Information)

### SSP1: Sustainability – The Green Road

#### Sketch

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

#### Additional Information

*Motivating forces:* Growing evidence of and accounting for the social, cultural, and economic costs of inequality and environmental degradation moves the world gradually, but pervasively, to prioritize progress towards achieving global and national development and sustainability goals, while reducing inequality (across and within economies). The shift is more pronounced in developed countries, which increasingly prioritize improvements in well-being over economic growth *per se*. Even in developing countries, where there is a continued focus on economic growth, goals are tempered by increased attention to ensuring this growth is broad-based and does not come at the expense of long-term degradation of local environments

This shift evolves over time and is not uniform. The gradual accumulation of evidence of the costs of inequality and environmental degradation is punctuated by periodic tragedies that bring these costs into stark relief. These events stimulate growing constituencies supporting change at the local, national, regional, and international levels. Over time, the initially disparate constituencies are mutually reinforcing, ultimately leading to effective and persistent cooperation and collaboration across these scales and between public organizations, the private sector, and civil society within and across all scales of governance, including local, regional, national, and international.

These trends open the door to formal and informal actions that, over time, help to fundamentally restructure the relationships within and between societies, and between humans and the environment. Policies shift to align incentives with development and sustainability goals, including measures such as the adoption and use of standardized measures of well-being to complement GDP; a shift in taxes and subsidies towards a stronger recognition of environmental considerations; a tightening of environmental regulation on the national and regional level; optimizing resource use efficiencies associated with urbanizing lifestyles; and improving the access of developing countries to international markets, including the opening of agricultural markets. As a result of these changing incentives, as well as evolving norms, there are further shifts in public and private behavior reflected in changing consumption and investment patterns. Many of these developments are slow to take hold broadly, and face some resistance and experience setbacks along the way. However, over time they become increasingly self-reinforcing. It is a bumpy road, but one that eventually moves most of the world in a more sustainable direction.

*Policies, institutions and social conditions:* Relatively effective and persistent cooperation and collaboration of national and international organizations and institutions, the private sector, and civil society help drive the transition from increased environmental degradation in the short-term to improved management of the local environment and the global commons over the longer term. For example, tighter controls on air pollution improve health in developing countries. Improvements in agricultural productivity through rapid diffusion of best practices and development of new cultivars and other technologies decrease challenges to food security. Research and technology development reduce the challenges of access to safe water.

New global institutions evolve to support cooperation on sustainable development, with flexible roles played by other actors. Reductions in corruption levels, policies calling for greater transparency in all sectors of society, and strengthening of the rule of law gradually lead to greater effectiveness of development policies.

*Human development:* A large emphasis is placed on education and providing access to health care. Policies aim at achieving universal access and promoting higher education levels and gender equality. Relatively high economic growth in low-income countries reduces poverty, and a global focus on increasing equity also increases social cohesion, while maintaining high levels of social and cultural diversity within and across countries. Increasing access to health care and



to safe water and improved sanitation in low-income countries reduces the burden of preventable diseases.

*Economy and lifestyles:* This development pathway implies that economic growth is relatively high in developing countries, although growth rates are moderated over time by a shift in emphasis from growth *per se* to well-being, equity, and sustainability. Inequality is reduced across and within countries. Markets are globally connected, but an emphasis on regional production reduces the incentives for specialization and limits the increase in trade volumes. Investment in environmental technology and changes in tax structures, including phase out of subsidies on fossil fuels, particularly coal and oil, lead to higher levels of resource efficiency, moderating overall energy and resource use over the longer term. Increased investment, lower taxes, and changing perceptions make renewables more attractive. The service sector grows relatively quickly. Consumption is oriented towards low material growth and lower resource and energy intensity, with a relatively low level of consumption of animal products.

*Population and urbanization:* Investments in human capital and rapid technological change accelerate the demographic transition in currently high fertility countries, leading to a relatively low population. Economic optimism sustains or increases fertility levels toward the replacement rate in currently low fertility countries. Urbanization, while still rapid in many developing regions of the world, increasingly is directed via growth of civil society, governance capacity and engaged decision-making to promote environmental benefits, and limit negatives associated with urban growth and cities, reducing the incentives promoting urban sprawl and urban population deconcentration. Cities become more consistent incubators and promoters of sustainability practices. Migration is at intermediate levels. Although increasing integration of labor markets allows people to move around more freely, improved regional livelihoods and the renewed emphasis on regional production reduce migration incentives.

*Environment and resources:* The value shift toward prioritizing environmental sustainability and associated policy focus on environmental protection and technology development implies that air and water pollution is likely to be low and results in improvements in environmental conditions and enhanced protection for vulnerable ecosystems and regions. Depletion of non-renewable resources is relatively low given the focus on environmentally friendly technology. Still, there are challenges with respect to the trade-offs between various resources (such as the use of bio-energy). Food security increases with attention paid to reducing the underlying drivers and increased investment in research and development. Land use is strongly regulated to avoid environmental tradeoffs.

*Technology:* Relatively rapid technological change is directed toward environmentally friendly processes, including energy efficiency, clean energy technologies, and yield-enhancing technologies for land. Strong investment in new technologies and research improves energy access and advances alternative energy technologies. Technology transfer is facilitated by international agreements on intellectual property rights and other issues.

*Challenges:* Challenges to mitigation are low because of high mitigative capacity brought about by rapid technological change as well as effective institutions and willingness to cooperate, facilitated by a broad orientation toward environmental sustainability in an urban-dominated economy. Challenges to adaptation are low because of reductions in vulnerability at the individual and societal levels, and the increased effectiveness of governance and institutions re-oriented toward cooperation and sustainability principles. Better-educated populations and high overall standards of living confer resilience to societal and environmental changes with enhanced access to safe water, improved sanitation, and medical care. Other factors that reduce vulnerability include, for example, the successful implementation of stringent policies to control air pollutants and reductions in energy, food, and water insecurity. If and when severe climate impacts do occur, coordination structures, e.g. integrated early warning systems, security alliances, disaster relief services, and risk reduction and resiliency promotion strategies are in place to assist those most at risk.

## **SSP 2: Middle of the Road**

### **Sketch**

*The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including improved living conditions and access to education, safe water, and health care. Technological development proceeds apace, but without fundamental breakthroughs. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Even though fossil fuel dependency decreases slowly, there is no reluctance to use unconventional fossil resources. Global population growth is moderate and levels off in the second half of the century as a consequence of completion of the demographic transition. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and to rapidly slow population growth. This growth, along with income inequality that persists or improves only slowly, continuing societal stratification, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes and constrain significant advances in sustainable development. These moderate development trends leave the world, on average, facing **moderate challenges to mitigation and adaptation**, but with significant heterogeneities across and within countries.*

## **Additional Information**

*Motivating forces:* In this world, socio-economic development occurs at moderate rates on average, but with substantial differences on a regional level. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others do less well. Moderate corruption levels and limited access to the rule of law slows the effectiveness of development policies.

*Policies, institutions and social conditions:* There is moderate awareness of the environmental consequences of choices when using natural resources. There is relatively weak coordination and cooperation among national and international institutions, the private sector, and civil society for addressing environmental concerns. While local environmental concerns, such as air quality, rank high on the agenda of many countries, implementation lags behind the ambitions. Globally this leads to an intermediate pathway for pollutant emissions.

*Human development:* There is some progress towards universal education, but education investments are not high enough to rapidly slow population growth, particularly in low-income countries. Access to health care and safe water and improved sanitation in low-income countries makes unsteady progress, with some countries benefiting from the resulting improvements to population health and productivity. Gender equality and equity slowly improve, particularly in countries with more sustainable development.

*Economy and lifestyles:* Moderate rates of development are reflected in economic growth patterns, with high growth for some low-income countries. Emerging economies continue their rapid development for an initial period, but experience a slowdown in growth rates as their economies mature. High-income countries continue to grow at moderate rates. As a result, per-capita income levels grow at a medium pace on the global average, with slow convergence of relative income levels between the bulk of developing and industrialized countries. Most countries are politically stable and associated globally connected markets function imperfectly. The flow of information and global access to markets are rather well established in most countries, although entry barriers to agricultural markets are reduced only slowly. Consumption is oriented towards material growth, with growing consumption of animal products.

Income distributions within regions improve with increasing national income, but inequities remain high in some regions. Poverty is a challenge for many disadvantaged populations conditions of extreme poverty particularly so. Tensions within and between countries periodically threaten to boil over, but do so only rarely, and never catastrophically. Conflicts over environmental resources flare where and when there are high levels of food and/or water insecurity coupled with political and economic instability

*Population and urbanization:* Population growth is moderate, with higher growth in low-income countries, slowing population growth in middle-income countries, and limited to negative population growth in most industrialized countries. Migration between countries continues at intermediate levels owing to the restriction of labor markets, but there are intermittent periods of



greater international migration when populations are challenged by food insecurity, conflict, and other factors. Urbanization proceeds at rates and in patterns consistent with historical experience in different world regions. Urbanization is particularly transformative in East and South Asia and sub-Saharan Africa. The transformation of cities resulting from the introduction of sustainable energy technologies and associated design proceeds at differing rates, with the highest rates in developed or rapidly developing urban contexts.

*Environment and resources:* Fossil fuel dependency slowly decreases, but access to global oil and gas markets continues to play a large role in international relations. Growing energy demand and no reluctance to use unconventional fossil sources lead to continuing environmental degradation even with reductions in resource and energy intensity. There is less progress in low-income countries. Moderate regulation of land use leads to a slow decline in the rate of deforestation.

*Technology:* There is some international cooperation and investment in research and technology on providing access to modern energy and promoting sustainable development. However, new energy and agricultural technologies developed in industrialized countries are only slowly shared with middle- and low-income countries, in part because of challenges to resolving intellectual property rights, legal rights, and other issues with technology transfer.

*Challenges:* Mitigation challenges are moderate in this pathway with a semi-open globalized economy and only moderate transformation toward environmentally friendly processes. Limits to mitigative capacity include the continued reliance on fossil fuels, including unconventional oil and gas resources, limited progress toward a urban sustainability transition, the moderate pace of technological change in the energy and agricultural sectors, and challenges in global cooperation on environmental issues.

Challenges to adaptation are moderate as global population growth, along with persisting income inequality (globally and within economies), societal stratification, urban growth in exposed and vulnerable locations, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes. Food and water insecurity continue to be problems in disadvantaged areas of low-income countries. There is only intermediate success in addressing air pollution or improving energy access for the poor as well as other factors that reduce vulnerability to climate and other global changes.

### **SSP 3: Regional Rivalry – A Rocky Road**

#### **Sketch**

*A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for*

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

### **Additional Information**

*Motivating forces:* Growing concerns with respect to international competitiveness and national security, aided by renewed interest in regional identity and culture, push societies to become more skeptical about globalization and increasingly focus on domestic or, at most, regional issues and interests. These developments lead step by step and over time to a world that is separated into regional blocks of countries with little interaction between them, resembling the Cold War period from 1945-1990, but with multiple poles. Competition, including periodic direct and proxy occurrences of conflict between regional blocs, results in weak progress in achieving sustainable development goals.

*Policies, institutions and social conditions:* Due to the focus on national security and sovereignty, government institutions dominate societal decision-making. Authoritarian regimes emerge or are strengthened in many parts of the world, leading on balance to diminished effectiveness of institutions. The remaining participatory societies are increasingly bound by a strong ethic of supporting national priorities. A considerable level of corruption results from the entanglement of the private and public sectors. Environmental policies have a very low priority in this world.

Global governance and institutions are weak, with a lack of cooperation and consensus; effective global leadership and capacities for problem solving are largely absent.

*Human development:* Investments in education are low and access to health care, safe water, and improved sanitation is limited, leading to large and poor populations in low-income countries with increasing burdens of preventable diseases, with limited opportunities for improving the situation. Gender equality and equity change little over the century.

*Economy and lifestyles:* Slow economic growth in all regions results from, among other factors, little international cooperation and low investments in education and in technology for development. Development proceeds slowly, with high inequalities across countries and persistent inequality within countries. There are pockets of extreme poverty alongside pockets of moderate wealth, with many countries struggling to maintain living standards. Trends work against the reduction of social stratification, with little improvement for disadvantaged population groups. Inequities are especially prevalent in cities. Consumption is material intensive. The world has de-globalized, and international trade, including energy resource and agricultural markets, is restricted because of security concerns.

*Population and urbanization:* Overall, global population growth is high as a result of the low education trends, slow economic development, and stalled demographic transitions, particularly in developing countries. At the same time, mortality rates are high in developing countries, with many children dying from preventable diseases (malnutrition, diarrheal disease, malaria). In high-income countries, economic uncertainty leads to low fertility. Combined with low levels of international migration, this leads to rapid aging in industrialized countries.

Urbanization is slow in all regions, due to slow economic growth that limits employment opportunities in urban areas, low international migration, and development patterns that make urban areas unattractive destinations for rural populations. However, disadvantaged populations continue to move to poorly planned settlements around large urban areas, particularly in low-income countries, often in places that are particularly vulnerable to extreme weather and climate events.

*Technology:* In general, technology development is very slow due to low investment levels and with very limited transfer of new technologies to other regions. Energy technology change is also slow and mostly directed to the exploitation of domestic fossil resources to improve energy security. Agricultural technology development is slow, especially with very limited transfer to developing countries.

*Environment and resources:* A low priority for addressing environmental concerns leads to serious degradation of the environment in some regions. Countries focus on achieving energy and food security goals within their own region. There is a push to maintain domestic energy supplies and develop unconventional fossil fuel resources. Domestic markets are highly regulated and uncompetitive. With little regulation in place, there is continued deforestation due to competition over land and rapid expansion of agriculture.

*Challenges:* Challenges to mitigation are high because of continued energy demand driven in part by high population growth and little progress in efficiency. Use of domestic energy resources results in some regions relying heavily on fossil fuels. More importantly, the absence of institutions to facilitate global cooperative action and limited governance resources, low technological capacity, and little investment in research and development lead to low mitigative capacity.

Challenges to adaptation are high because of highly vulnerable human and natural systems; because global governance, institutions, and leadership are relatively weak in addressing the multiple dimensions of vulnerability; and because institutional effectiveness within regions and countries is mixed at best. Low investments in human capital contribute to high vulnerability. Meager progress on development goals results in poorly educated populations in some regions, with many disadvantaged populations without access to safe water, improved sanitation, polluted air, health care, and other factors that increase vulnerability. These factors lead to low adaptive capacity in many parts of the world.

#### **SSP 4: Inequality – A Road Divided**

##### **Sketch**

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

*to adaptation are high for the substantial proportions of populations at low levels of development and with limited access to effective institutions for coping with economic or environmental stresses.*

### **Additional Information**

*Motivating forces:* In this world inequalities increase, both between and within countries, driven mainly by a combination of skill-biased technology development and reduced access to higher education. The technological development is rapid, favors entrepreneurial individuals and those with post-secondary education, and leads to less demand for unskilled labor. This enables economic growth to be supported by a relatively small proportion of the population with high education, reinforcing the trend toward inequality.

On a large scale, this is seen as increasing socioeconomic fragmentation—between world regions, between nations within regions, and between sub-national regions and groups—continuing and accelerating trends that could be seen at the start of the 21st Century. The fall in inequality that was seen in some regions halts and the rise of an extremely wealthy few among the merely wealthy that began at the turn of the century continues, with wealth and income increasingly concentrated.

*Policies, institutions and social conditions:* A large share of the population has limited access to national institutions, which focus on the globally connected high-tech economy and operate mainly in the interests of top earners and businesses. International institutions and power structures increasingly focus on and serve the needs of the globally connected economy. This concentration of power favors effective cooperation between nations and businesses to agree on and implement action if it is in their interest to do so. Vulnerable groups have little representation in these organizations and lack the capacity and resources to organize themselves.

*Human development:* Weak political power for less-affluent groups is compounded by fewer economic opportunities, as they face limited access to credit. Among other effects, this limits opportunities for low-educated households to pursue a better education, reducing social mobility. In developing countries with less well-educated populations, public expenditures on education focus on producing a small, highly educated elite at the expense of broader-based investments in education, leading to much slower growth of the middle class than would otherwise be expected and in many cases worsening income inequality.

*Economy and lifestyles:* The most distinctive aspect of the economy is its divergence both within and across countries into a high-tech, knowledge- and capital-intensive economy to which the relatively well off and highly educated parts of the population belong, and a low-tech, labor-intensive economy in which the substantial fraction of the population that is less well off participates. The high-tech economy globalizes with highly connected international businesses and workers and open trade, but many people are left outside this system. In general the absolute income of all or most people increases, but the relative position of many—in some countries, the



majority—worsens. At the national level, economic growth tends to be medium in industrialized and middle-income countries, while low-income countries lag, with slow economic growth. As a consequence, most middle-income countries see their per capita incomes gradually converge toward those of the high-income countries, while most low-income countries (and some middle income countries) are left behind. However, there are distinct leading and lagging economies even within each of these groups and in nearly all countries income inequality increases. The global middle class, which was expanding rapidly at the turn of the century, still expands, but sluggishly, as economic gains at the low end of the global income distribution begin to slow. Support for those in the middle classes falters, with weakening social security measures and poorly regulated labor markets. The high and middle income groups have fairly high consumption lifestyles, but the low income groups are limited to low consumption levels and very limited mobility.

*Population and urbanization:* In industrialized countries, economic uncertainty for most of the population leads to relatively low fertility and low population growth, and in some cases decline with a medium pace of urbanization but with accelerated population deconcentration. In low- and middle-income countries, urbanization rates remains high. In low-income countries this is induced by the large cohorts of young people in rural areas that result from high fertility rates as well as by a lack of promising employment opportunities and increasing security concern in rural areas. In all countries, the richer group physically separates itself from the poorer population, moving to enclaves within cities with a high demand for skilled labor and (mainly in the wealthier countries) smaller towns with highly specialized job markets. In low and middle-income countries, physical separation is partly reflected in large and growing peri-urban slums. Rural areas and less-favored urban areas are largely, although not entirely, left behind by these developments. Migration is high for richer groups, but difficult for low-income groups. Due to the lack of access to health care and other services, mortality is relatively high for poorer groups, especially in low-income countries, but also for those poorer groups in medium and high income countries.

*Technology:* Within the high-tech economy, technology development and diffusion are rapid, with high transfer rates between countries and firms. However, outside this main economic system, technology diffusion is slow and people rely more on local resources. Social instability of cities including increasing economic inequities and diminished governance capacity result in limited ability to experiment with and implement new sustainability energy technology on a widespread basis. Informal energy economies and procurement strategies in urban areas further limit the progression toward energy sustainability.

*Environment and resources:* Environmental awareness is mainly limited to the direct living areas of middle and high-earning groups, while little attention paid to global environmental problems and their implications for poorer groups in society. As a consequence, there is a stark division in environmental conditions. On the one hand, there are areas that the world cares about, close to living areas of middle and high-earning groups and where these groups spend their vacations,

which are well-managed and environmentally clean. On the other hand, resource and production areas and many other places that are out of sight do not get much attention and become deteriorate.

Energy resources are strongly affected by oligopolistic structures in the fossil fuel market, which lead to underinvestment in opening up new resources in many regions of the world, causing oil and gas prices to rise and volatility to increase due to changes in demand and disruptions of supply. In this uncertain environment, companies diversify into carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Renewable technologies benefit from the high technology development, bringing them to competitive cost levels with fossil energy sources. The low-carbon energy projects that succeed are typically those that provide large private returns. These well-funded risk-mitigation strategies drive a new era of innovation that provides effective and well-tested energy technologies, but are often pursued without adequate protection of affected groups. Those groups lose assets and livelihoods, which increases their vulnerability to climate change.

For agriculture, the productive areas of the world are dominated by industrialized agriculture and monocultural production. Crop yields would be typically high in large-scale industrial farming, but low for small-scale farming. Food trade is global, but access to markets is limited, increasing vulnerability for non-connected population groups. Land use is highly regulated in high and middle income countries, but largely unmanaged in low-income countries leading to tropical deforestation.

*Challenges to mitigation are low* in this world due to the pool of expertise and technologies that can be rapidly brought to bear if there is a strong push towards lower emissions. The concentration of power, especially to global businesses, enables them to develop and apply effective climate policies, once it is in their interest to act. Challenges to adaptation are high, given the relatively high inequality and substantial proportions of populations at low levels of development and with limited access to effective institutions for coping with economic or environmental stresses.

## **SSP5: Fossil-fueled Development – Taking the Highway**

### **Sketch**

*Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for*

*economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary. While local environmental impacts are addressed effectively by technological solutions, there is relatively little effort to avoid potential global environmental impacts due to a perceived tradeoff with progress on economic development. Global population peaks and declines in the 21st century. Though fertility declines rapidly in developing countries, fertility levels in high income countries are relatively high (at or above replacement level) due to optimistic economic outlooks. International mobility is increased by gradually opening up labor markets as income disparities decrease. The strong reliance on fossil fuels and the lack of global environmental concern result in potentially **high challenges to mitigation**. The attainment of human development goals, robust economic growth, and highly engineered infrastructure results in relatively **low challenges to adaptation** to any potential climate change for all but a few.*

### **Additional Information**

*Motivating forces:* Two major factors enable a break with historical patterns that showed a lack of regional convergence in institutional arrangements and economic growth. First, the economic success of emerging economies and more recently least developed countries gives rise to an emergent global middle class that has been lacking in most regions of the world. The new middle class stabilizes global economic development by promoting robust growth in demand for services and goods especially in cities. The new middle class also fosters the more widespread adoption of world views oriented towards market solutions and participatory societies in many world regions. In particular, developing countries aim to follow the fossil- and resource-intensive development model of the industrialized countries. Second, the digital revolution enables a global discourse of a significant and increasing share of the population for the first time in human history leading to a rapid rise in global institutions and promoting the ability for global coordination.

*Policies, institutions and social conditions:* On a national and regional level, institutional changes are initiated to foster competitive markets, leading – by and large – to more effective institutions with lower levels of corruption, strong rule of law, and the removal of market entry barriers for disadvantaged population groups. Social cohesion, gender equality, and political participation are strengthened in most world regions. As a consequence, social conflicts are gradually decreased, although the more pervasive adoption of participatory and market oriented world views creates significant tension with traditional views during a transition phase.

On the international level, countries pursue a global “development first” agenda and increasingly

cooperate on economic, development, and security policies. Regional conflicts are met with assertive international action, and decline with rapid development and decreasing levels of social conflict. Institutions that further market penetration and lower trade barriers are strengthened, leading to accelerated globalization and high levels of international trade. International cooperation on environmental policies is much more limited due to a perceived trade-off between development and environmental goals for global, long-term issues.

*Human development:* Development policies emphasizing education and health are put in place to accelerate human capital development. These policies, aided by rapid economic development, lead to a strong reduction of extreme poverty and significantly improved access to education, safe drinking water and modern energy in the medium term.

*Economy and lifestyles:* Economies become increasingly globalized over time with high levels of international trade. The gross world product at the end of the century is very high. Per capita incomes in developing countries increase rapidly, leading to strong convergence of interregional income distributions and a measurable decline of income inequality within regions. At the same time industrialized countries continue their focus on economic growth, driven in part by consumerism and resource-intensive status consumption, including a preference for individual mobility, meat-rich diets, and tourism and recreation. Developing countries rapidly adopt these consumption patterns.

*Population and urbanization:* Global population peaks and declines in the 21st century, a result of rapid fertility declines in developing countries driven by improving education, health, and economic conditions. In high income countries, fertility is above replacement due to optimistic outlooks for economic conditions. International mobility is increased by gradually opening up labor markets as income disparities decrease. Migration from poorer to wealthier countries buffers the effect of aging populations in industrialized countries. All regions reach high levels of urbanization. Urban planning and land use management play crucial roles, but struggle to keep up with the rapid migration of rural population into cities in the first few decades of the century. While urbanization rates converge over time, urban structure and form develop in different world regions to reflect historic patterns and prevailing local and national policies. This includes dense mega-cities in densely populated countries, and large metropolitan areas with significant urban sprawl in other regions of the world.

*Technology:* Technological progress is seen as a major driver of development and economic growth. Fostered by widespread technology optimism, investments in technological innovation are very high, with a focus on increasing labor productivity, fossil energy supply, and managing the natural environment. In continuation of the current shale revolution, fossil resource extraction is maximized at low cost, and local externalities of fossil energy production (e.g. health effects) are well controlled by continued technological advancements in the fossil energy sector. Due to the strong reliance on fossil energy, alternative energy sources are not actively pursued.

*Environment and resources:* Environmental consciousness exists on the local scale, and is focused on end-of-pipe engineering solutions for local environmental problems that have

obvious impacts on well-being, such as air and water pollution particularly in urban settings. On the other hand, individualistic lifestyles give rise to local opposition against engineering solutions that affect local environments (NIMBY). Agro-ecosystems become more and more managed in all world regions, facilitated by productivity improvements and the diffusion of resource-intensive management practices in the agricultural sector. The resulting large increases in agricultural productivity and a peaking and declining world population can support high per capita food consumption and meat-rich diets globally. However, some deforestation continues due to incomplete regulations. In the long run, land and environmental systems are highly managed across the world, and there is a general tendency to decouple human-engineered systems from natural systems as much as possible.

*Challenges:* The strong reliance on fossil fuels and the lack of global environmental concern result in potentially *high challenges to mitigation*. The attainment of human development goals, robust economic growth, and highly engineered infrastructures results in relatively *low challenges to adaptation* for all but a few.