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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.

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

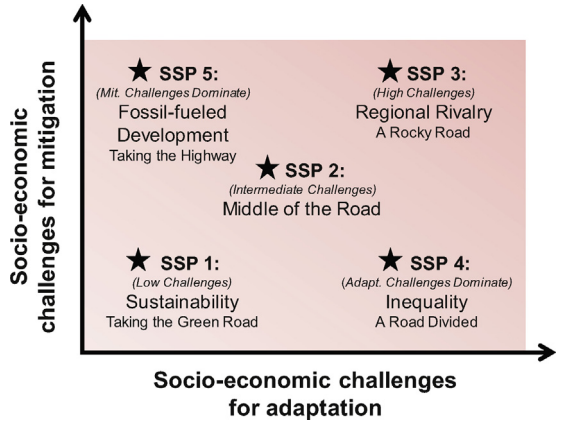

Fig. 1. Five shared socioeconomic pathways (SSPs) representing different combinations of challenges to mitigation and to adaptation. Based on Fig. 1 from O'Neill et al. (2014), but with the addition of specific SSPs.

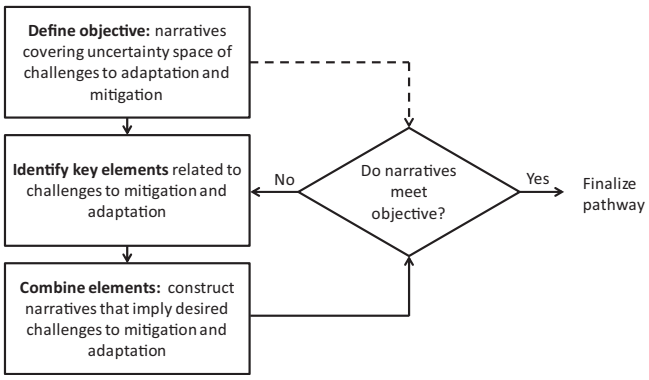

Fig. 2. Flow diagram of process for developing SSP narratives.

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[1]. 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

[1] For descriptions of the process, see Ebi et al. (2014), and 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

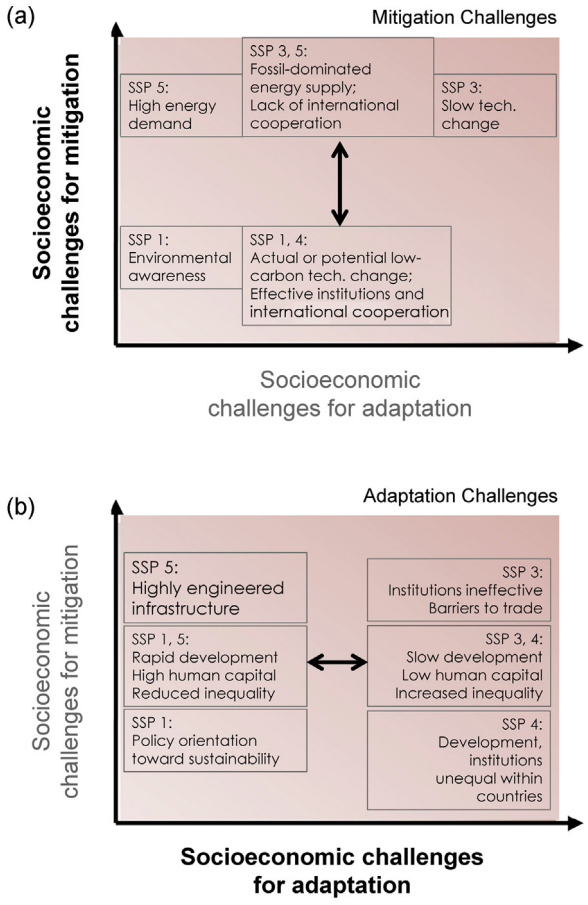

Fig. 3. A summary of SSP elements that contribute to high or low challenges to mitigation (a) and adaptation (b). Elements listed toward the top or bottom of the challenges space in figure (a) apply to pathways with high or low challenges to mitigation, respectively, while elements listed toward the 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						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
Economy & lifestyle					
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
Policies & institutions					
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
Technology					
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
Environment & natural resources					
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

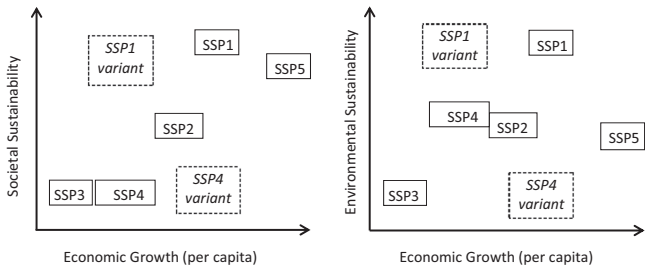

Fig. 4. Illustrative mapping of SSPs to a space defined by elements of the SSP narratives as opposed to consequences of the narratives for challenges to mitigation and adaptation.

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.

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