

Climate and socio-economic scenarios for climate change research and assessment: reconciling the new with the old

Detlef P. van Vuuren · Timothy R. Carter

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Abstract A suggestion for mapping the SRES illustrative scenarios onto the new scenarios framework of representative concentration pathways (RCPs) and shared socio-economic pathways (SSPs) is presented. The mapping first compares storylines describing future socio-economic developments for SRES and SSPs. Next, it compares projected atmospheric composition, radiative forcing and climate characteristics for SRES and RCPs. Finally, it uses the new scenarios matrix architecture to match SRES scenarios to combinations of RCPs and SSPs, resulting in four suggestions of suitable combinations, mapping: (i) an A2 world onto RCP 8.5 and SSP3, (ii) a B2 (or A1B) world onto RCP 6.0 and SSP2, (iii) a B1 world onto RCP 4.5 and SSP1, and (iv) an A1FI world onto RCP 8.5 and SSP5. A few other variants are also explored. These mappings, though approximate, may assist analysts in reconciling earlier scenarios with the new scenario framework.

1 Introduction

In climate change research and assessment, scenarios are widely used to explore the future long-term socio-economic and environmental consequences of human activities. This includes the analysis of future emissions and mitigation potential, the modelling of climate system responses to changing atmospheric composition, and studies of climate change impacts, adaptation and vulnerability (IAV). Scenarios also play a key role in transferring information across the different research communities related to these different topics. The development of scenarios, and especially scenarios designed to serve multiple communities,

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D. P. van Vuuren (✉)
PBL Netherlands Environmental Assessment Agency, Bilthoven, The Netherlands
e-mail: detlef.vanvuuren@pbl.nl

D. P. van Vuuren
Department of Geosciences, Utrecht University, Utrecht, The Netherlands

T. R. Carter
Finnish Environment Institute (SYKE), Climate Change Programme, Helsinki, Finland

is a time-consuming exercise. The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES–IPCC 2000) can be used as an example: it took about 4 years to develop these scenarios and publish them, and then several years more before SRES-based climate model projections became widely available for impact studies (Moss et al. 2010). Some reasons for the long time lags are the development process itself (to ensure quality and community buy-in) and the processing time of the climate modelling step. Partly as a result of this, the same scenarios tend to appear in the literature over long time periods.

In 2006, the climate research community initiated a process to develop new scenarios (Moss et al. 2010). In light of the long time-lags, mentioned above, it is important to ensure that any new scenario framework can also be related back to the existing literature on scenarios. First of all, such cross-referencing would ensure that published IAV and mitigation studies based on earlier scenarios still contribute usefully to climate change assessments (ensuring continuity in the literature). Secondly, as with previous exercises, the development of new scenarios will also take time, so in the absence of new information some researchers may be compelled to adopt elements from earlier scenarios. Here again, cross-referencing can be helpful for the logical and consistent selection of different scenario components.

The new scenario framework comprises two key elements (Kriegler et al. 2012; van Vuuren et al. 2012b, 2013): (1) Representative Concentration Pathways (RCPs), and (2) Shared Socio-economic Pathways (SSPs). The RCPs represent trajectories for the development of emissions and concentrations of different atmospheric constituents affecting the radiative forcing of the climate system over time. These pathways may be affected, to a greater or lesser extent, by the introduction of mitigation policies. The SSPs, in contrast, provide narrative descriptions and quantifications of possible developments of socio-economic variables (such as population growth, economic development and the rate of technology change) that characterise challenges to mitigation and to adaptation. The SSPs are described elsewhere in this Special Issue (O'Neill et al. 2013). The RCPs and SSPs can be brought together into a two-dimensional RCP/SSP matrix. Here, each cell describes a plausible trajectory of emissions and concentrations resulting in a given level of forcing by 2100 that is consistent with and superimposed on a plausible pathway of socio-economic development.

The narrative storylines and the final quantification of the SSPs for population, urbanisation and economic growth have not been available to researchers until very recently. Moreover, the quantifications by Integrated Assessment Models (IAMs) to provide data on emissions and land use still have to be undertaken. Meanwhile, climate modellers have already generated new climate projections based on the RCPs (e.g., Taylor et al. 2012), while some IAV modellers have produced initial impact estimates (e.g., Hanasaki et al. 2013; Portmann et al. 2013).

In this context, the current paper concentrates on establishing linkages both within the new scenarios framework (relating SSPs and RCPs) and between the framework and the existing scenarios literature. This can then: (i) assist IAV researchers in using (elements of) existing scenarios in studies based on the new framework, and (ii) aid interpretation in assessments that compare findings using the new scenarios framework with results based on existing scenarios. Its main focus is on comparisons with the SRES scenarios (SRES - IPCC 2000), though some other studies are also referenced. The emphasis on the SRES is because of the prominence of these scenarios in existing climate change research literature. It should be noted that linkages between the SRES scenarios and the new framework, where they can be identified, are only approximate, given the differences in both concept and detail between the scenarios. One example of such a difference concerns the treatment of climate policy,

which is absent from the SRES scenarios but accommodated within the new scenarios framework. Other differences are highlighted below.

The next sections offer comparisons of existing scenarios with SSPs (Section 2), with RCPs (Section 3) and with combinations of SSPs and RCPs (Section 4). Finally, Section 5 puts forward some closing suggestions for analysts wishing to reconcile earlier scenario-based studies with the new framework presented in this Special Issue.

2 Comparing SSPs to earlier scenarios

Two main axes play a role in the new scenario framework: the level of radiative forcing of the climate, represented by the RCPs, and alternative trajectories of future socio-economic circumstances, represented by the SSPs. The so-called basic SSPs are formulated as socio-economic development pathways, assuming no impacts from climate change and in the absence of new climate policies. Such assumptions (similar to those of the SRES scenarios) imply that most of these basic SSPs are expected to result in emission levels consistent with the higher-end of the RCP range (SSP1 may offer an exception). It is only by introducing mitigation policies (a component of Shared Policy Assumptions or SPAs in the framework) that emission levels can be orientated towards the lower-end of the RCP range (Kriegler et al. 2013).

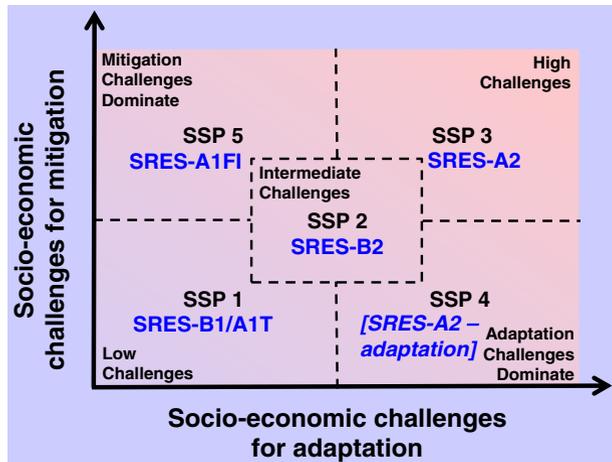
It has already been stated that aspects of the IPCC SRES scenarios, as well as some other global scenarios described below, have been and continue to be used in IAV studies. Two IPCC Working Group II chapters provide in depth analyses of the application of climate, environmental, land use and socio-economic scenarios in IAV studies (Carter et al. 2001, 2007). The latter provides numerous examples of studies that have employed SRES scenarios at different scales and for different sectors. Moreover, since the AR4 there have been many new studies (e.g. Arnell et al. 2013; Ciscar et al. 2011; Lung et al. 2013; Tubiello and Fischer 2007). Most studies make particular use of the narrative storylines associated with the scenarios, along with information on key drivers such as population and income and global model-based projections of climate change. The SRES storylines have also been used as a contextual frame for developing finer-scale scenarios, with some of the scale issues being addressed through various downscaling approaches, both qualitative (Rounsevell and Metzger 2010) and quantitative (van Vuuren et al. 2010).

2.1 Comparing SSP storylines with those of earlier scenarios

Unlike the SRES, which were largely exploratory scenarios, SSPs are designed around outcomes that make it easier or harder to respond to the challenges of climate change. SSPs are located in one of five domains that are defined by challenges to mitigation and challenges to adaptation (O'Neill et al. 2013) – see also Fig. 1). It should be noted that there may be multiple realisations of scenarios with similar adaptation and mitigation challenges in any one domain.

It is of interest to examine how the SRES and other socio-economic scenarios map onto this challenges space. Van Vuuren et al. (2012a) recently made a review of several global environmental scenario studies, including: the UNEP's Global Environmental Outlook, the Millennium Ecosystem Assessment (MA), the International Assessment of Agricultural Knowledge, Science and Technology for Development, SRES, the World Energy Outlook, the Food and Agriculture Organization's World agriculture towards 2030/2050 study, the work of the Global Scenario Group and work by the International Food Policy Research

Fig. 1 A suggested mapping of the SRES scenarios (in blue) onto the five domains of socio-economic “challenges space” occupied by SSPs (based on O’Neill et al. 2013) and expanded)



Institute (references and descriptions of these studies can be found in Van Vuuren et al. 2012a). A summary of the key scenario characteristics is presented in Table 1. Six scenario archetypes were identified (columns in Table 1) based on key scenario characteristics such as main development objectives, technology development (including the role of environmental technology), environmental protection, policies and institutions and vulnerability to climate change. The mapping suggested by van Vuuren et al. (2012a) assists in a re-interpretation of existing scenarios, including SRES, in terms of challenges to adaptation and mitigation (blue entries in Fig. 1).

The mappings on the leading diagonal in Fig. 1 provide examples of paired adaptation and mitigation challenges. Several factors leading to low mitigation challenges also lead to low adaptation challenges, including a sufficient degree of good governance, rapid technology development, and low population development. Such a world is described, for instance, by the eco-friendly and globalised B1 world, but also in the high-tech world represented by the A1T scenario and possibly the regional sustainable development scenario represented by the B2 storyline (though the B2 quantification focuses on medium developments for all parameters). At the other extreme, the significant challenges to both adaptation and mitigation (SSP3) have been associated with a divided world, with high population growth and poorly developed institutions and governance, similar to A2. Finally, the actual quantification of the B2 scenario in SRES presents an intermediate set of challenges consistent with SSP2. It is worth noting that some elements of the SRES A1B storyline also resemble the SSP2 storyline.

One can also imagine situations in which adaptation and mitigation challenges are not coupled, which then shifts elements of the storyline and quantification away from the leading diagonal in Table 1 towards either SSP4 or SSP5. For the SSP4 storyline, with high adaptation challenges but low mitigation challenges it is not easy to find an earlier SRES equivalent. The SRES A2 scenario could again fit this description from an adaptation perspective, where large numbers of the world’s population are highly vulnerable to climate change. However, the SSP4 storyline also requires that solutions to the mitigation challenge be available. This can be done by assuming an even more divided world in which inequality within each region results in a group of poor people, who are highly vulnerable to climate change impacts, co-existing with another richer group, who are responsible for the majority of greenhouse gas emissions. This is not part of the original A2 storyline, though elsewhere

Table 1 Key assumptions and approximate mappings of archetypal scenario “families” (van Vuuren et al. 2012a)

Archetype	Global sustainable development	Business as usual	Regional competition	Economic optimism	Reformed markets	Regional sustainability
SSP mapping	SSP1	SSP2	SSP3/SSP4	SSP5		
Economic development	Ranging from slow to rapid	Medium	Slow	Very rapid	Rapid	Medium
Population growth	Low	Medium	High	Low	Low	Medium
Technology development	Ranging from medium to rapid	Medium	Slow	Rapid	Rapid	Ranging from slow to rapid
Main objectives	Global sustainability	Not defined	Security	Economic growth	Various goals	Local sustainability
Environmental protection	Proactive	Both reactive and proactive	Reactive	Reactive	Both reactive and proactive	Proactive
Trade	Globalisation	Weak globalisation	Trade barriers	Globalisation	Globalisation	Trade barriers
Policies and institutions	Strong global governance	Mixed	Strong national governments	Policies create open markets	Policies target market failures	Local actors
Vulnerability to climate change	Low	Medium	Mixed – varies regionally	Medium-high	Low	Low
Other mappings:						
SRES	B1 (A1T)	B2 ^(a)	A2	A1FI		B2 ^(a)
GEO3/GEO4	Sustainability First		Security First	Markets First	Policy First	
Global Scenario Group	New Sustainability Paradigm		Barbarisation	Conventional World	Policy Reform	Eco-communalism
Millennium Assessment	Technogarden		Order from Strength		Global Orchestration	Adapting Mosaic

^a The B2 storyline emphasized a focus on environmental and social issues from a regional perspective; in the quantitative elaboration, however, the choice was made to use medium projections for all relevant variables. Therefore, the B2 scenario is listed here in two columns. *Note: This table summarises key assumptions in very general terms. Where differences within a set of scenario families exist, broad ranges are indicated. For references to scenario exercises, see text*

in the literature the Order from Strength scenario in the Millennium Ecosystem Assessment emphasises a similar development. Finally, the converse case is presented by SSP5 – a world with high challenges to mitigation, which could be matched to a fossil-fuel dependent A1FI world, but also with low challenges to adaptation, again requiring a novel interpretation of A1FI as a world offering economic and technological solutions to address widespread poverty and other causes of vulnerability.

SSPs have been positioned in relation to scenarios archetypes at the top of Table 1. This facilitates comparison with other scenario studies, which can also be important for putting climate change in the wider context covered by other scenario exercises. Entries in the rows at the base of Table 1 are attempts to match specific scenario descriptors for SRES, GEO3/GEO4, GSG and MA to the six archetypes. While mapping is not always fully possible, in most cases there is sufficient overlap in the storylines.

The preceding analysis demonstrates that mapping between SSPs and the SRES scenarios is possible though not completely straightforward. For instance, different SRES scenarios may coincide with the current formulation of SSP1 (B1 and A1T), depending on how the SSP1 storyline is further elaborated (lifestyle change versus a focus on low to zero carbon technologies). Second, elements of the SRES-B2 scenarios are included in more than one SSP (partly because the quantification of the B2 scenario seems to deviate somewhat from the B2 storyline). Finally, for some SSPs (e.g. SSP4) it is difficult to find equivalent scenarios in the (SRES) literature.

2.2 Interpreting elements of previous scenario quantifications

In addition to climate projections, scenarios of population and income level are often adopted in large-scale, model-based IAV studies. This section offers a brief analysis of the assumptions commonly made for these variables, in order to discern whether similar trends can be seen across the range of earlier studies categorised on the basis of their storylines. Emissions of greenhouse gases and air pollutants are compared in more detail for the SRES scenarios and the RCPs in Section 3, partly because the quantification of SSPs for these variables is not yet available. In addition, Section 4 briefly discuss the role of land use assumptions.

2.2.1 Population

Figure 2 shows the population scenarios included in several global environmental assessments published in the last few years. While some typical patterns emerge, the overview also shows that there is considerable overlap between the storyline families across the various assessments. For instance, there seems to be little relationship at all between the type of scenario and the quantitative projections of population for the OECD region. Nearly all projections end up in a relatively narrow range from 1 to 1.4 billion, i.e. near the UN medium projection of 1.3 billion. On average, the scenarios included in the Global Sustainable Development category are slightly lower than the other categories. Interestingly, the UN scenarios (low/high) cover a much wider range than projections in the assessments. For the non-OECD regions, the range of projections included in the various assessments by the end of the century is much wider. While the full range is from 5 to 13 billion people, the range can be reduced to 5–10 billion by excluding the somewhat outdated SRES A2 projection. Here, there is a very clear link between the storylines and the quantitative projections: global sustainable development projections and economic optimism scenarios end up at around 5–8 billion, business-as-usual scenarios mostly lead to projections around 9–10 billion while regional competition is associated with values of 10 billion or more.

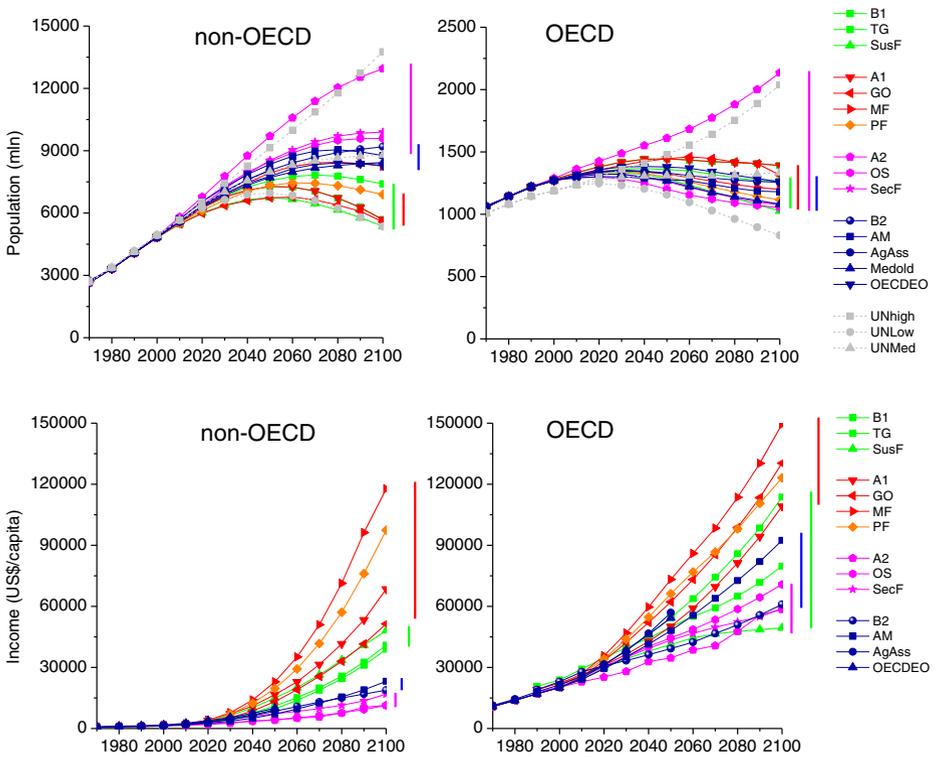


Fig. 2 Population projections (*upper panels*) and income projections (*lower panels*) in selected global environmental assessments at 10 year intervals out to 2100, classified into different scenario families. GEO5 scenarios are Sustainability First (SusF), Security First (SecF)

2.2.2 Income

For economic projections, typical patterns for each of the various scenario families can be seen for both the OECD and non-OECD regions (Fig. 2). For the non-OECD region, regional competition scenarios end up at around 10,000 US\$/capita in 2100, medium scenarios at around 20,000 US\$/capita, the global sustainability scenarios at close to 40,000 US\$/capita and the economic optimism scenarios at 60–100,000 US\$/capita (all data are expressed as market-exchange rates from their original publications). The OECD projections usually remain above those of the non-OECD, with the highest degree of convergence in the global sustainability and economic optimism scenarios. This implies that the ranges could be used to derive income levels that may be consistent with the new SSP storylines.

3 Comparing RCPs to SRES scenarios

The four representative concentration pathways (RCPs) were selected to reflect the range of radiative forcing levels reported in the published literature (Van Vuuren et al. 2011). The RCPs range from a very low forcing level (RCP2.6) to a high emissions baseline scenario

(RCP8.5), with two intermediate pathways (RCP4.5 and RCP6.0). Each RCP comprises basic information on future atmospheric composition and land use change that are required to undertake climate model simulations. Details of the RCPs are to be found in a collection of nine papers published in this journal and summarised in van Vuuren et al. (2011). This section considers how the RCPs relate to earlier SRES scenarios.

3.1 Comparing RCP and SRES projections of atmospheric composition

Adjustments in atmospheric composition, through changes in greenhouse gas and aerosol concentrations, are the primary contributors to additional radiative forcing of the climate system. Some of these constituents are also of direct concern to IAV analysts, because of their direct environmental and health impacts.

CO₂ comprises the single most important climate forcing factor in most scenarios but also affects the productivity of many terrestrial plants and aquatic organisms, as well as being a direct cause of ocean acidification. Differences in CO₂ concentrations constitute the key factor that differentiates the RCPs. A comparison of four RCPs, six SRES illustrative scenarios and the earlier IS92a scenario¹ is provided in Table 2 and Fig. 3 (using results of the simple carbon cycle model included in the MAGICC model – Meinshausen et al. 2011a). The results show that in terms of CO₂ concentrations, RCP4.5 and B1 are very similar, RCP6.0 compares reasonably well to a level between B2 and A1B and RCP8.5 is somewhat comparable to the A2 scenario up to mid-century, though it later diverges towards A1FI.

Comparing scenarios for air pollution is more complicated, as these atmospheric constituents can exhibit large regional variations. The global emissions and average concentration of several air pollutants (sulphur dioxide, nitrogen species, ozone precursors and ozone concentrations) of the RCPs are lower than the SRES set (Lamarque et al. 2011; Van Vuuren et al. 2011). The reasons for this include 1) that the RCPs tend to include both climate policy and air pollution control and 2) that since the publication of SRES, emissions in many developing countries have decreased more rapidly than expected (see for instance Klimont et al. 2013). Interestingly, combinations of air pollutant control assumptions and climate policy have resulted in a rather narrow emission range across the RCPs (e.g. for ozone). Various air pollutants can be of central importance for aspects of both mitigation and impact assessment. Nitrogen emissions provide one example, contributing directly to climate change, responsible for eutrophication of aquatic ecosystems but also capable of stimulating growth of some terrestrial ecosystems, and hence CO₂ sequestration (de Vries et al. 2009). Another prominent example is surface ozone, given its role in forcing but also direct health and vegetation impacts (Ainsworth et al. 2012). Surface ozone increases only under RCP8.5 and declines in the other three RCPs (Lamarque et al. 2011). Overall, the closest resemblance of surface ozone concentration shown by all four RCPs is to projections under the SRES B1 scenario (Table 3). As the range for ozone and its precursors is narrower than found in the published literature, analysts studying joint climate and air pollution effects might look beyond the RCPs for a representative range of air pollution scenarios.

3.2 Comparing RCP and SRES climate projections

A crucial issue for climate scientists, as well as for researchers wishing to make use of climate projections, is to understand how the RCP climate projections compare to their

¹ One of a set of six IS92 scenarios published prior to SRES by the IPCC (Leggett et al. 1992).

Table 2 Carbon dioxide concentrations estimated for the four representative concentration pathways (RCPs) based on the MAGICC model (Meinshausen et al. 2011a) and for the six SRES illustrative scenarios and IS92a scenario based on the Bern-CC and ISAM models (averaged – IPCC 2001). PreInd is pre-industrial

Year	Representative concentration pathway				SRES illustrative scenario							
	RCP2.6	RCP4.5	RCP6.0	RCP8.5	B1	A1T	B2	A1B	A2	A1FI	IS92a	
PreInd	278	278	278	278	278	278	278	278	278	278	278	
2000	369	369	369	369	368	368	368	368	368	368	368	
2010	389	389	389	389	387	388	387	390	388	388	389	
2020	412	411	409	416	411	411	407	419	416	416	414	
2030	431	435	429	449	435	438	427	451	448	452	442	
2040	440	461	451	489	460	469	451	487	486	500	472	
2050	443	487	478	541	485	499	476	527	527	561	504	
2060	442	509	511	604	506	526	502	568	574	632	538	
2070	438	524	550	677	522	548	528	606	628	709	575	
2080	432	531	594	758	534	565	556	644	690	793	615	
2090	426	534	636	845	542	575	585	680	763	879	662	
2100	421	538	670	936	545	579	616	710	846	964	713	

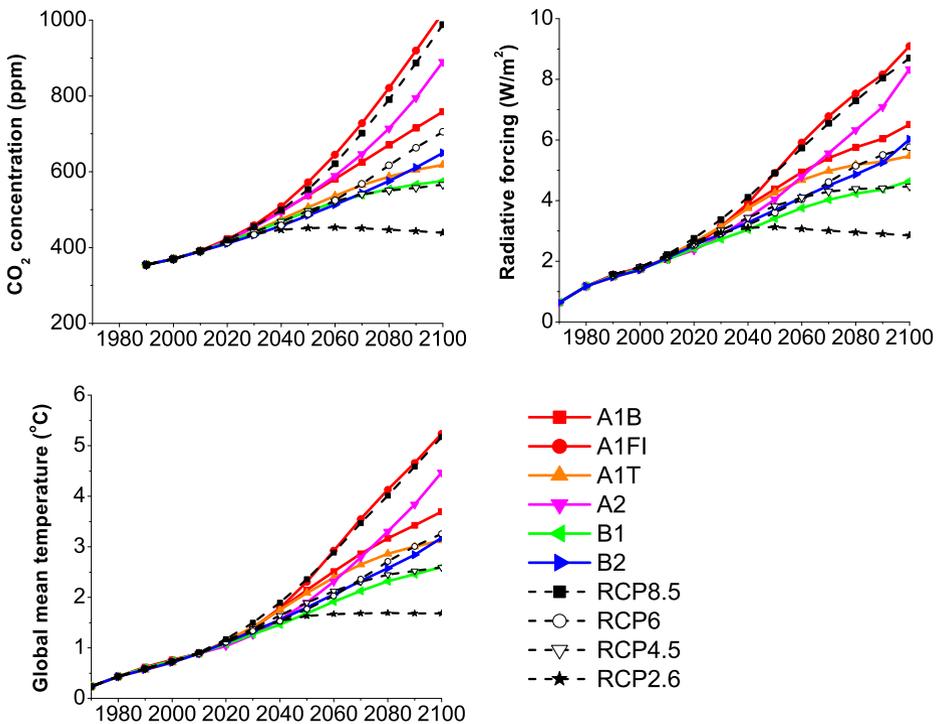


Fig. 3 Trends in CO₂ concentration, radiative forcing and temperature at 10 year intervals out to 2100 for the RCPs and IPCC SRES based on the MAGICC model (Meinshausen et al. 2011b). Data provided by Michiel Schaeffer (2013)

Table 3 An approximate mapping of SRES and IS92a scenarios onto the RCPs, with respect to CO₂ concentration, radiative forcing and temperature response (from Fig. 3) and tropospheric ozone concentration (Lamarque et al. 2011)

RCP	SRES and IS92a mapping	
	CO ₂ /Climate	Tropospheric ozone
8.5	A2/A1FI	B1
6.0	B2/ IS92a/A1B	B1
4.5	B1	B1
2.6	<i>Post-SRES (E1)^a</i>	B1

^a E1 is an aggressive mitigation scenario initiated from an A1B scenario developed using the IMAGE model (Lowe et al. 2009)

earlier SRES-based equivalents. Until very recently, the climate outcomes of the latest co-ordinated model runs of the SRES-scenarios, primarily for A1B, A2 and B1 (Meehl et al. 2005) were heavily applied in IAV assessments worldwide, either using the global model outputs directly or applying downscaling methods to obtain finer resolution information.² Earlier climate model runs pre-dating the CMIP-3 exercise, that were assessed in the IPCC Third Assessment Report (Cubasch et al. 2001) were also based on SRES forcing, mainly using A2 and B2, and are still applied in some IAV studies.

The RCPs were specified well in advance of the IPCC AR5 so that a new co-ordinated set of simulations with updated versions of climate models could be undertaken. This exercise, equivalent to but even more ambitious than CMIP-3, was labelled CMIP-5 (Taylor et al. 2012). New RCP-based climate model outputs are now available and are gradually being applied by researchers worldwide. Differences between climate projections based on SRES and those based on RCPs are a function both of updated and refined versions of the climate models, as well as different forcing scenarios. In the AR5 report, several tools are used to indicate the contribution of these two factors. However, the interest here is to assess which of the RCPs approximates the forcing found in the SRES scenarios (or any other forcing scenarios used to generate climate projections used by analysts), so that earlier results can be judged against emerging RCP-based outcomes.

For climate, CO₂ concentration offers a useful initial guide for comparison (see Table 2 and Fig. 3). This implies that RCP8.5 falls somewhere between the SRES A2 and A1FI scenarios; RCP6.0 occurs below A1B but above B2, though it most closely resembles the earlier IS92a. RCP4.5 is closest to SRES B1, and a little above A1T. There is no SRES scenario that achieves CO₂ concentrations as low as RCP2.6, which is not surprising, given that the SRES scenarios do not include explicit mitigation policies. A more comprehensive comparison is possible for global radiative forcing values. Obviously, these show similarities to the CO₂ concentrations, although there can be important regional variations in forcing that will affect the climate (e.g., due to aerosol effects or surface albedo changes). However, the focus here is on global mean forcing, and in Fig. 3 trajectories of combined radiative forcing during the 21st century are shown for the four RCPs and the six SRES illustrative scenarios,

² CMIP-3 results are available from the original data host site at the Lawrence Livermore Laboratory (PCMDI – http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php) as well as from the IPCC Data Distribution Centre (DDC – <http://www.ipcc-data.org/>). Derivative information is also available for users from many national and international portals.

which have been estimated using the MAGICC model (Meinshausen et al. 2011a; Wigley and Raper 2001). The mapping here is similar to that for CO₂ concentration.

MAGICC can also be used to calculate global mean temperature change in response to this radiative forcing (Fig. 3 – values for both sets are from the MAGICC model). Here, the temperature response to SRES A1FI appears much closer to that of RCP8.5 than for radiative forcing. It should be noted that this comparison does not account for the influence of local climate-forcing factors such as induced by albedo changes and aerosols.

Considering that the majority of SRES-based climate projections have been for A2, A1B, B1 and B2, with a limited number for A1FI, a preliminary mapping would give the outcomes shown in Table 3. Although no SRES-based climate model projections match the RCP2.6 projections, a number of so-called “post-SRES” mitigation scenarios were evaluated in the IPCC TAR (Morita et al. 2001) and other mitigation scenarios in the AR4 (Fisher et al. 2007). Climate model simulations have been conducted for some of these. An example shown in Table 3 is the E1 scenario, which is initiated from a variant of SRES A1B and stabilises at about 3 Wm⁻² in the 22nd century (Johns et al. 2011). Projections from 10 climate models are available for this scenario, and have also been applied in IAV studies (e.g., Pardaens et al. 2011; Watkiss 2011).

4 Combining RCPs and SSPs and comparing to SRES scenarios

The scenarios that emerged from the SRES process, and other similar global exercises, comprised a small set of plausible, internally consistent representations of future developments. Their saliency, legitimacy and credibility was ensured through extensive peer review and stakeholder feedback. They were typically released only as a single, integrated package, ready for application. In contrast, the RCPs and SSPs have been developed largely independently of each other by a large research community, albeit within a process that was determined early on (Moss et al. 2010) and guided by a scenario matrix architecture for achieving the integration of the two (Van Vuuren et al. 2013). It is only by combining RCPs with SSPs (thus reconciling the socio-economic and climate projections) in the next step of the process that coherent and integrated characterisations of the future can be crafted.

4.1 A summary mapping using the scenario matrix

A stylised form of the scenario matrix architecture is presented in Table 4, with SSPs along the horizontal and RCPs along the vertical. Entries along the axes are suggestions of how SRES scenarios might map, separately, onto SSPs (in blue) and RCPs (in red). This draws on the discussion in Sections 2 and 3, respectively. Entries in the matrix proper (in black) show where SRES scenarios approximate an SSP-RCP combination. These are the SRES scenarios that would seem to lend themselves to comparison with scenarios based on the new framework. Note that SSPs are organised and clustered in Table 4 according to challenges to adaptation, as an interpretative aid for IAV researchers. This means that from bottom to top on the vertical scale an ascending range of climate forcing is shown, and from left to right on the horizontal scale increasingly demanding challenges to adaptation are implied, defined in relative terms in the narratives and quantitatively by socio-economic variables.

Table 4 Scenario matrix architecture showing suggested SRES mappings onto SSPs (in blue, based on Fig. 1) and onto RCPs (red). The cells in the matrix have entries (black font) where the same SRES scenario approximates a combination of an RCP and an SSP. Here, not only the reference SRES scenarios are mentioned, but also possible positioning of mitigated SRES scenarios. Square brackets indicate mappings that are less robust. The E1 scenario is a mitigation scenario derived from the A1B storyline and leads to a forcing close to RCP2.6

Challenges to adaptation:		Low		Medium	High	
		SSP1	SSP5	SSP2	SSP3	SSP4
Reference	SRES	B1 / A1T	A1FI	B2	A2	[A2]
8.5 Wm ⁻²	A2 / A1FI		A1FI		A2	[A2]
6.0 Wm ⁻²	B2 / A1B			B2		
4.5 Wm ⁻²	B1	B1	← Mitigated SRES	Mitigated SRES	→	
2.6 Wm ⁻²	[E1]	← Mitigated SRES			→	

4.2 Land use assumptions in different scenarios

One element of the scenarios that poses some problems of interpretation, both in terms of comparing across RCPs and SSPs as well as in relation to earlier scenarios, is the projection of land use and land cover change (LUCC).

- First of all, LUCC influences climate change. Here, there are two important routes: via greenhouse gas emissions, and through biophysical processes such as albedo change (Sitch et al. 2005). The greenhouse gas emissions associated with land-use changes are already included in the concentration figures discussed in Section 3.1 (they can simply be added to energy and process related emissions). Land use related emissions are also included in the RCP emission profiles described by Meinshausen et al. (2011b). The climate impacts of biophysical processes related to LUCC are important for regional climate change. Here, much more uncertainty exists (e.g., Pitman et al. 2012).
- Second, LUCC can also contribute both to mitigation challenges (e.g. determining the potential for bio-energy) and to adaptation challenges (e.g. influencing runoff and water demand). These relationships are also uncertain. For instance, with reference to the RCP axis, mitigation policies could alternatively lead to more forests (as a result of reforestation) or less forests (due to increased bio-energy use). Similar ambiguities exist across the different socio-economic storylines, in particular at the regional scale, as a result of an interplay between key drivers such as land use policies, trade policies, population change and dietary preferences.

All-in-all, it can be concluded that the relationships between climate scenarios and LUCC are complex, and there is still little experience in this area. For instance, only the IMAGE integrated assessment model provided geographically explicit LUCC maps for SRES (IMAGE-team 2001). For the RCPs, LUCC scenarios have been made available by Hurtt et al. (2011) and, finally, for the SSPs, LUCC scenarios still need to be developed. At this point, it is not obvious how the impacts of land use change on the outcomes of RCP-forced climate models can be interpreted in relation to scenarios with other land use patterns. In light of these complexities, no additional guidance is provided here on the comparison or interpretation of different land use scenarios.

5 Conclusions

This paper has presented suggestions for positioning earlier scenarios used in climate change research in the context of the new scenarios framework described in this Special Issue. Clearly, the relationship between the RCP/SSP scenarios and the SRES scenarios is not perfect. Nevertheless, the results are instructive and may help to ensure continuity in the application and interpretation of scenarios.

Focusing specifically on the six SRES illustrative scenarios that have been and continue to be widely applied in impact, adaptation and vulnerability assessments, an attempt was made first, to match SRES storylines to those for the SSPs and second, to search for correspondences in projections of atmospheric composition, radiative forcing and climate between SRES scenarios and RCPs. Finally, these mappings were pooled using the scenario matrix framework outlined in van Vuuren et al. (2013), resulting in the following suggestions for reconciling the new scenarios with the old:

- A2 world \approx RCP 8.5 (climate) and SSP3 (socio-economics)
- B2 or A1B worlds \approx RCP 6.0 (climate) and SSP2 (socio-economics)
- B1 world \approx RCP 4.5 (climate) and SSP1 (socio-economics)
- A1FI world \approx RCP 8.5 (climate) and SSP5 (socio-economics)
- No SRES-based climate projection maps onto RCP 2.6, though some SRES-related mitigation scenarios might come close (e.g. the E1 scenario)
- The SRES range of projections for ozone and some other air pollutants is not replicated in the RCPs, which all resemble B1 and underestimate the published range.

While these mappings are approximate, it should be remembered that scenarios, by their nature, are not intended to provide precise predictions of the future. Rather they are tools for exploring plausible future developments and examining associated uncertainties. It is to be hoped that these suggestions are useful to readers wishing to relate earlier scenario-based analyses to this new framework.

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