Pathways and Scenarios: 10 Things to Know About the IPCC Scenario Framework

Summary

The new generation of IPCC-led scenarios are constructed from a combination of representative concentration pathways and associated radiative forcing, socioeconomic pathways and climate policy assumptions. These aspects define the three dimensions of the scenario matrix; a framework for exploring contingencies, uncertainties and costs in the changing climate of future worlds.

This article is aimed at anyone seeking a referenced overview of what constitutes IPCC scenarios and provides answers to the questions:

1. What are scenarios?
2. What are pathways?
3. Why do we need scenarios?
4. Have they been used before?
5. How are these new scenarios different?
6. What are radiative forcing levels and RCPs?
7. What are SSPs?
8. What are SPAs?
9. How are all of these things related?
10. What can we use this framework for?

We then explore what has been done since the new generation framework was introduced - the post-2014 scenarios work – and add final remarks on how the approach shapes regional or national studies. A more detailed look at research applications is given in an appendix at the end of the article.

1. What are scenarios?

The meaning of scenarios in the climate change research context is much the same as in common parlance; a scenario is a postulated sequence or development of events. But we can be more specific. In this context, a scenario is the integrated product of socio-economic, climate change, and climate-related policy assumptions (Nakicenovic et al., 2014), and is a plausible description of how the future might unfold. The assumptions that frame a scenario can be altered to provide a set of different scenarios. In this way, scenarios can help us to understand the possible range of alternative futures and the uncertainty associated with them.

2. What are pathways?

Pathways are plausible trajectories of development in certain fields (eg. policy and governance, socio-economical, technical, energy-industrial). They evolve over time and can be combined with other assumptions or conditions to create scenarios. In the case of research on climate change, the IPCC has developed a framework in which the relevant pathways are representative concentration pathways (RCPs) and shared socio-economic pathways (SSPs) (Moss et al., 2010). These can be combined, along with shared policy assumptions (SPAs) and sometimes projected climate change, to construct scenarios. In this way these different aspects (RCPs, SSPs and SPAs) define three dimensions of a scenario matrix.

Research in the climate adaptation and mitigation field may also incorporate other types of pathways such as transition, policy or decision pathways. These are used to answer specific research questions and describe changes in social, technical, economic or political systems. Transition pathways, for instance, are explored by more detail by Foxon et al. (2013) and Turnheim et al. (2015).

3. Why do we need scenarios?

Under the IPCC (2014) definition, scenarios are devices for analysing situations in which outcomes are uncertain. In practice, the climate change scenario matrix provides researchers and policy-makers with a framework to explore the relationships between different socio-economic conditions and policies, different levels of climate change, and the costs and challenges associated with adaptation or mitigation. They are often used in models (Integrated Assessment Models, macroeconomic models and sectoral models as well as in climate modelling) to help quantify these changes and understand uncertainties.

The scenario framework also provides a consistent approach and a platform for researchers, so that their efforts can be coordinated and build on previous work.

4. Have they been used before?

Yes. The IPCC has been working with scenarios for some time, producing early scenarios in 1990 (SA90) and 1992 (IS92). The last set of scenarios from the IPCC were presented in the Special Report on Emissions Scenarios (Nakicenovic et al., 2000) and are known as the SRES scenarios. These scenarios used a sequential approach based on a linear causal chain beginning with socioeconomic conditions. Socioeconomic conditions determined greenhouse gas emissions, which in turn were used as inputs to climate models via their radiative forcing (effect on solar heating). The outputs of the climate models then were used in evaluations of vulnerability to the climate impacts.

This sequential process turned out to be very time-consuming. Work on the SRES scenarios started in 1997; in 2001 the first climate model results using these scenarios as inputs were assessed, but it was not until the IPCC's Fourth Assessment Report in 2007 – a decade after inception – that a more complete set of SRES-driven climate scenarios were available and impact, adaptation and vulnerability research was published and assessed by the IPCC. By this time a new generation of climate models were being reported and inconsistencies arose. Since 2010 a newer 'scenario matrix architecture' has been adopted which is expected to replace SRES.

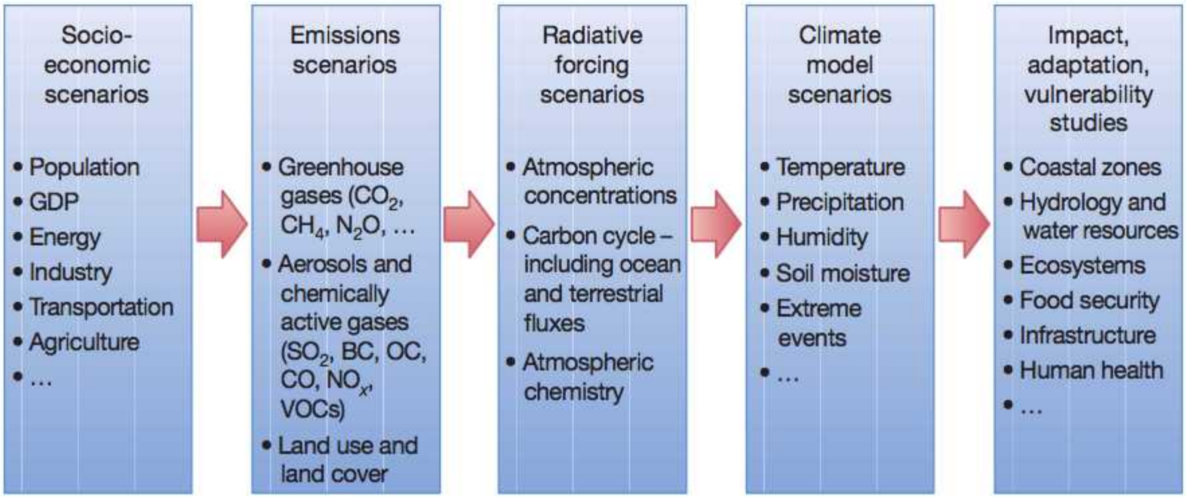

Fig. 1 – The old, sequential approach to scenario construction. After Moss et al. (2010)

5. How are these new scenarios different?

The new generation of scenarios uses a parallel approach (Moss et al., 2010), to shorten the overall process and to encourage interaction between research communities. In this format, the first step is the specification of different pathways of radiative forcing (see fig. 2).

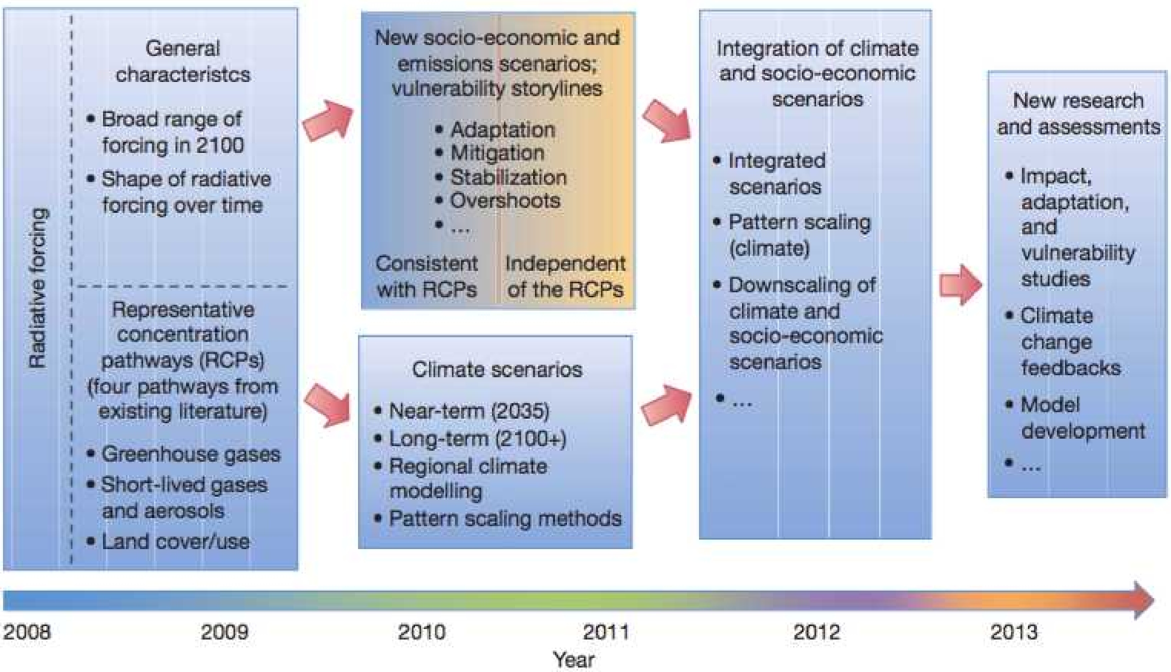

Fig. 2 – The new, parallel process for scenario development. After Moss et al. (2010)

6. What is radiative forcing?

Radiative forcing is the effective change in amount of solar energy received per second sunlight per square metre of land (W/m^2). Radiative forcing is determined by changes in: concentration of greenhouse gases (eg. CO_2, CH_4, N_2O), clouds, aerosols such as sulphate aerosols that reflect incoming sunlight, and changes to the land surface that alters its albedo, or reflectivity. Chart 05 in the IPCC AR5 Summary for Policymakers shows how the different factors which determine radiative forcing stack up against one another, and what the associated uncertainties are.

In essence, radiative forcing is a measure of the increase in heating of the Earth's surface due to changes in the atmosphere or to the Earth's surface. It does not, however, tell us by how much the temperature, rainfall or frequency of extreme weather events will change around the world; this question must be answered by comprehensive climate modelling that considers the intricacies of the ocean-atmosphere climate system.

RCPs, or representative concentration pathways, are the means by which a level of radiative forcing is specified. The RCPs contain information on future levels of greenhouse gases, aerosols and land cover.

The research community specified four different representative concentration pathways; these were chosen as a manageable number of pathways that covered the full range of emissions scenarios with adequate separation, and included information on forcing agents and land cover for use by the climate modelling community (van Vuuren et al., 2011). These four pathways are quoted in reference to the resultant radiative forcing; the number after 'RCP' indicates the amount of radiative forcing (in W/m^2) that each pathway stabilises at around or after 2100, or in the case of RCP 8.5, exceeds by 2100. The RCPs each produce different climatic futures, see chart 07 of the IPCC AR5 Summary for Policymakers for an overview.

7. What are SSPs?

SSPs are socio-economic pathways that consist of quantitative and qualitative elements that pertain to society, energy, economy and environment. They are reference pathways in that they contain no climate-related policy interventions or impacts.

SSPs are envisioned in a two-dimensional 'challenges space', with the degree of challenges to mitigation on one axis and the degree of challenges to adaptation on the other. The idea is that the different pathways are defined by the magnitude of the challenges a future society would face in adapting to or mitigating climate change if that socioeconomic pathway was pursued. These challenges refer to the characteristic of the society, not to the magnitude of climate change or stringency of the mitigation policy – as these factors are explicitly included in other dimensions of the scenario framework.

In practice, variables in six broad categories are represent in the SSPs: demographics, human development, economy and lifestyle, policies and institutions (but not climate policies), technology, and environment and natural resources. Five SSPs have been developed that cover the challenges space and are described by narratives and quantitative aspects where possible (O’Neill et al., 2015).

Fig. 3 – Placement of the five SSPs in the challenges space. After O’Neill et al. (2015)

An abridged example of one such narrative, for the most optimistic pathway SSP1, is below. The rest can be found in the contribution by O’Neill et al. (2015).

SSP1 describes a pathway in which the world shifts towards a more sustainable path, as society increasingly understands and responds to the social, cultural and economic costs of environmental degradation and inequality. Increasingly effective collaboration of local, national and international organisations and institutions, the private sector and civil society leads to improved management of the global commons. A demographic transition to a relatively low population is facilitated by educational and health investments. An emphasis on overall human well-being gradually displaces the priority of economic growth. With a smarter and more committed approach to achieving development goals, inequality is reduced within and across countries. Technological advancements improve resource efficiency. Increased investment, financial incentives and changing perceptions make renewable energy more desirable. Consumption is oriented towards lower material growth and lower resource and energy intensity.

A society that follows the SSP1 path will experience relatively low challenges to mitigation due to growth of renewable energy and environmentally friendly technologies, institutions that can facilitate international cooperation and relatively low energy demands. It will likewise experience relatively low challenges to adaptation due to reductions in inequality and strong institutions from global to national scales.

In the SSP narratives, drivers of high challenges to mitigation are a fossil fuel-dominated energy supply, combined with a lack of international cooperation on global environmental issues, and exacerbated by high energy demand and slow technological change (O’Neill et al., 2015). These features naturally only apply to certain SSPs (see fig. 4a).

Meanwhile high challenges to adaptation are hypothesised to be driven by slow development, low investments in human capital, and increased inequality (O’Neill et al., 2015). These problems may be exacerbated by ineffective institutions and barriers to trade.

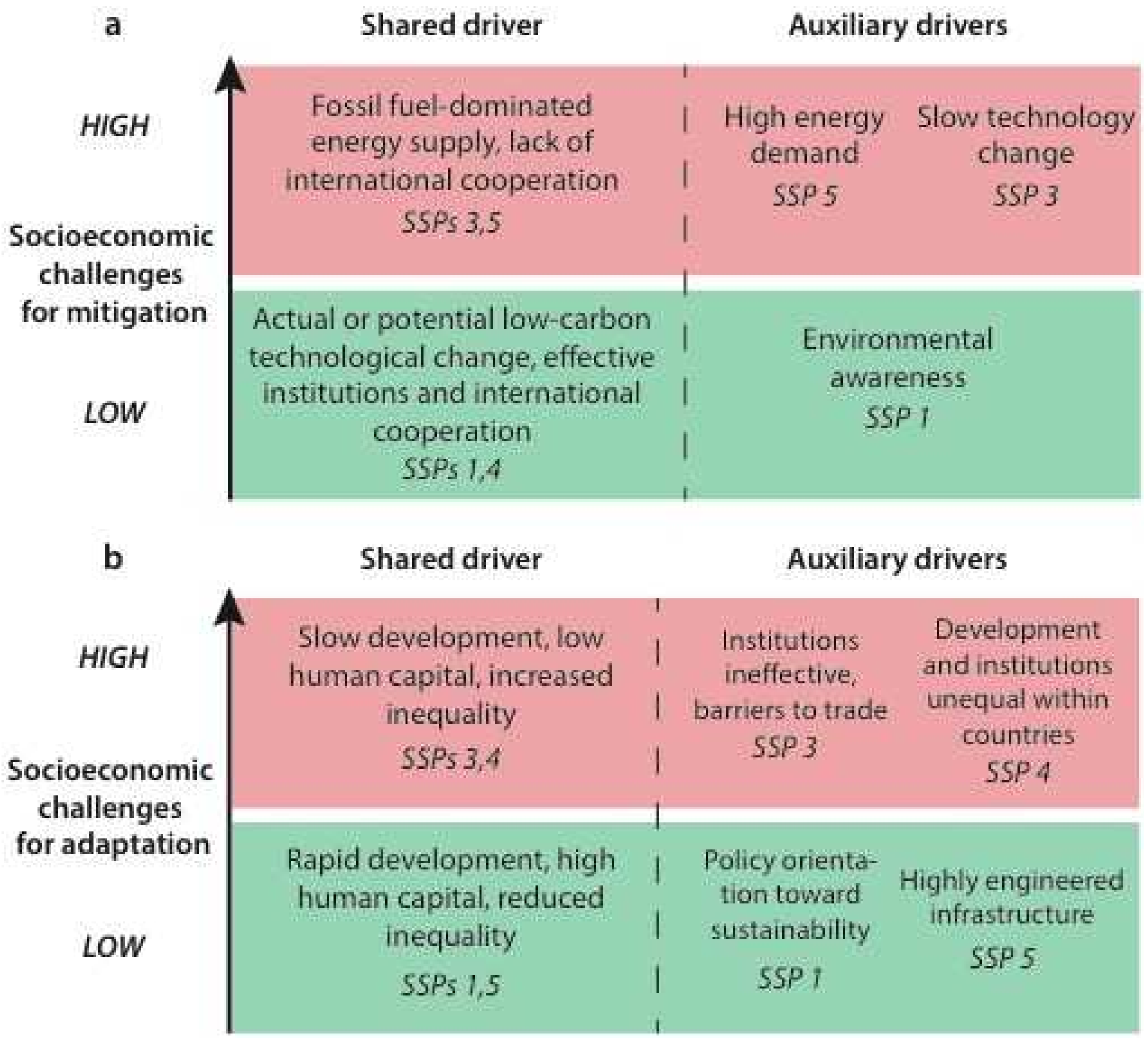

Fig. 4 – Narrative aspects associated with low or high challenges to mitigation (a) and adaptation (b), and the SSP they are a feature of. Figure modified after O'Neill et al. (2015).

8. What are SPAs?

SPAs are shared policy assumptions which have direct relevance to climate. Assumptions about climate policy are fundamental in linking socioeconomic futures with radiative forcing and climate outcomes. Their introduction enables researchers to systematically explore the costs and effectiveness of different adaptation and mitigation policies for different combinations of SSPs and RCPs.

What distinguishes policies in SPAs to those in SSPs is their motivation. The test is: would you expect the policy and its stringency to be deployed in the reference, no-climate-policy scenario? If yes, the policy belongs in the SSPs. But if it is deployed and/or tightened only in a mitigation scenario, it should be in the SPAs. For instance, any kind of tax on greenhouse gas emissions is part of the SPAs, likewise the implementation of an international climate adaptation fund. Conversely, development policies such as improving energy access, urban planning, infrastructure, health services and education are motivated in their own right, and thus fit into SSPs rather than SPAs – even though they have implications for mitigation or adaptation (Kriegler et al., 2014).

SPAs should elucidate three aspects of climate policies: 1) **climate policy goals**, such as emissions targets (though note this causes overlap with RCPs, we'll look at that interplay later); 2) **policy regimes and measures**, which are introduced to reach policy goals. These might include differentiated carbon taxes, an international emissions trading scheme, low carbon technology subsidies, regulatory policies etc.; 3) **implementation limits and obstacles** that are not part of an SSP, and might be based on the exclusion of certain policy options for given regions or sectors over certain timeframes if those policy measures do not appear feasible in that case. For example, certain regions might be expected to remain outside an international agreement for some time.

Like SSPs, SPAs include quantitative and narrative aspects. The narratives include information on the different timing of participation of regions and nations in emissions mitigation regimes, as well as describing the mitigation stringency across participating regions or countries; is it globally uniform or regionally differentiated? Narratives also elucidate the nature of climate policies; are fiscal or regulatory policies preferred? To what extent are mitigation efforts aimed at fossil fuels or land-use and land-cover change? Do policies focus on demand-side measure (behavioural changes, efficiency) or on upstream solutions such as technological improvements?

On the adaptation side, SPA narratives include information on institutional policies to support adaptation, for instance the implementation of an international technology transfer agreement; the quality and strength of governance leading adaptation measures, which would be weakened for example by corruption or conflicts of interest; and how effectively the policies are implemented (Kriegler et al., 2014).

Quantitative elements include the allocation of emissions permits to different regions, carbon price differentials between regions and sectors, a timetable for adoption of a global climate policy regime, regional low carbon technology targets, land use related policies such as forest protection and bioenergy constraints. In terms of adaptation quantitative elements would include the size of an international adaptation fund set up to assist vulnerable countries, and timetables for implementing regional adaptation plans (Kriegler et al., 2014).
Naturally, SPAs at the global and century scale have to be generic in construction; a detailed formulation of the climate policy landscape in 2050 would require too precise assumptions and invite redundancy given any perturbations.

9. How are all of these things related?

The elements discussed so far all fit into the new *climate change scenario matrix architecture*. Bit of a mouthful, but this is what draws the strands together and is a powerful tool for evaluating future eventualities.

A matrix is just a box made up of cells, with a given number of dimensions. In this case, we are dealing with a three-dimensional matrix, just like a three-dimensional space, with the axes defined by RCPs, SSPs and SPAs. This provides a framework for assessing a manageable number of discrete futures, spanning the range of plausible possibilities.

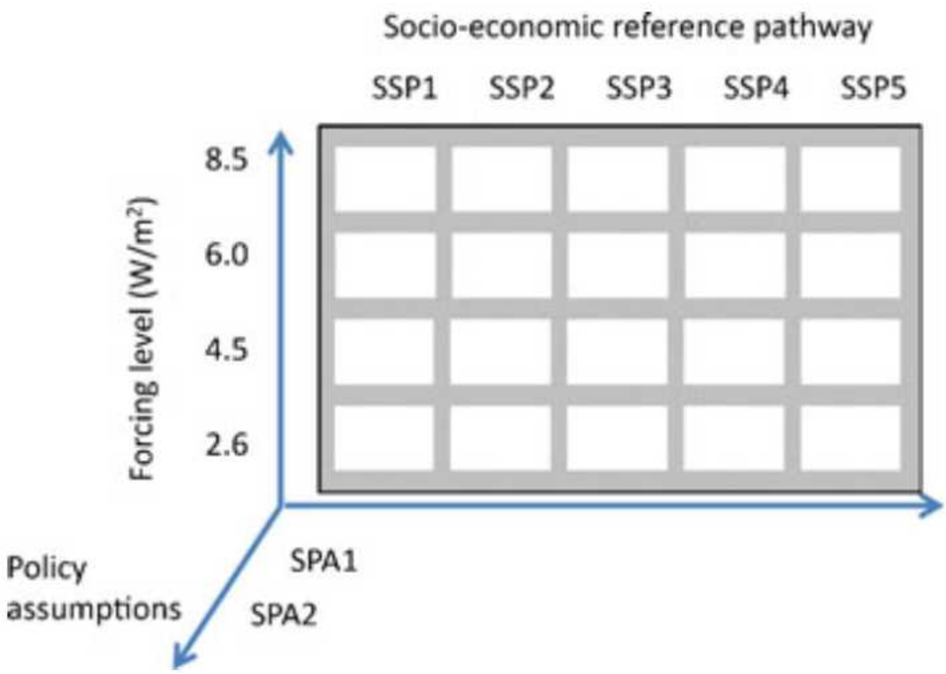

Fig. 5 - Matrix architecture: radiative forcing (specified by the RCPs), SSPs and SPAs specify orthogonal axes. Cells represent scenarios formed by a combination of pathways. After Van Vuuren et al. (2014)

As mentioned earlier, the Radiative forcing axis with its RCPs is the starting point for the process, and forms the intersection between socio-economic and climate research. Climate modellers take the RCPs as inputs for their models in order to produce assessments of future globally averaged and regional climate and the uncertainty associated with these projections. Climate sensitivity, a metric that characterises the response of the global climate system changes to radiative forcing, is associated with a lot of uncertainty. This is because climate system is incredibly complex and efforts to assign quantitative outcomes to variables such as temperature, precipitation and extreme weather events – divided over the whole world – must therefore be given within a range of uncertainty. This uncertainty in climate change outcomes can be graphically represented as in Fig. 6.

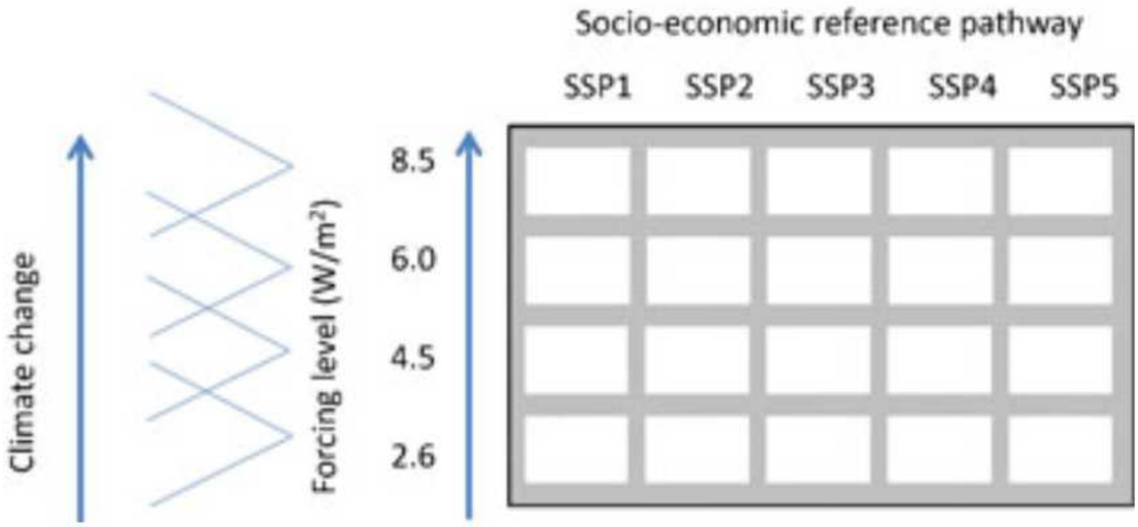

Fig. 6 – Uncertainty in climate outcomes for each forcing level is schematically indicated.

Another point to mention is that when it comes to inclusion in this framework, SPAs must include only elements that are not specified in RCPs or SSPs. As alluded to earlier, the climate policy goals aspect of SPAs would involve emissions targets, which would clearly overlap with RCPs. In order that SPA choice and RCP choice do not pre-specify one another, this overlap should be removed for the purposes of the scenario matrix. Likewise, some adaptation policy goals may overlap with other societal development goals in the SSPs, and this crossover should be avoided for matrix functionality (Kriegler et al., 2014).

At this point we can specify two types of SPAs: 1) a full SPA that includes all mitigation and adaptation policy targets, thus embedding the RCP and possibly aspects of an SSP in it; 2) a reduced SPA that excludes mitigation policy goals, at least as far as they relate to emissions reductions and forcing outcomes. The reduced SPA can therefore feature in the scenario matrix, and it is the reduced SPA that must be used if variation of policy assumptions for a given RCP-SSP combination are to be explored (Kriegler et al., 2014).

10. **What can we use this framework for?**

The matrix structure provides a means for pursuing a range of research questions, and for classifying studies. Indeed, studies can be classified according to the scenarios that they use, develop or evaluate, by placing them in the relevant cells of three-dimensional framework (van Vuuren et al., 2013). By populating a communal matrix with references to relevant studies, research connectivity is improved. In the literature this use is referred to as *heuristic*, meaning that the matrix can be used as an interactive framework.

Post-2014 scenarios: what's new

The most recent published IPCC research was the 1.5 degrees Special Report (IPCC 2018). This report presented results using climate change mitigation policy scenarios which include policy pathways towards a desired goal (e.g., the 1.5 °C goal). It focused on comparing pathways that get us to 1.5 °C vs. pathways that get us to 2 °C. This consideration of very stringent low-carbon policies (to achieve deep cuts in emissions required for 1.5-2°C) elaborates SPAs to include model scenarios with much higher investment and climate finance as well as land use changes towards bioenergy and/or expansion of forests. It is also worth noting that this was the first IPCC report to consider interaction of climate change scenarios with the UN's 2030 Agenda for Sustainable Development. Chapter 4 of the report examined the trade-offs and synergies with all 17 goals of the framework.

And finally ..

Finally, it should also be noted that IPCC-led scenarios are often used as a starting point for other work looking at specific regional or national applications. Other (non-IPCC) research takes IPCC scenarios as a starting point for further elaboration to create more nationally relevant scenarios to be used together with regional or national models that can offer higher resolution and deliver ever more detailed climate change assessments. Further information about several such projects can be found on weADAPT:

IMPRESSIONS - High-end climate change scenarios covering global, European and regional/local scales
AdaptCost - The AR4 scenario framework was used together with two global IAMs to provide results for Africa
FRACTAL - Investigates RCP scenarios with a regional climate model (RCM) for Africa (CORDEX-Africa)
CIRCE - The AR4 scenario framework was used with RCMs to develop assessments of projected climate change for the Mediterranean region

The appendix to this article provides a more detailed look at research applications for: a) the characterisation of baseline uncertainty – a range of different interpretations of individual SSPs as constructed by modelling teams; b) systematically exploring scenarios; c) the characterisation of costs for mitigation, adaptation and costs of residual impacts – the role of different socio-economic developments and climate policies.

Conclusion

The new generation of IPCC-led scenarios are based on a three-dimensional matrix; the dimensions defined by representative concentration pathways and associated radiative forcing, socioeconomic pathways and climate policy assumptions. This framework supports coordination across the climate change research communities and provides a basis for systematic analysis of key questions of mitigation and adaptation under different climate and socioeconomic futures.

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Appendix: Research Applications

This section gives further detail into applications of the scenario architecture.

a) *For the characterisation of baseline uncertainty*

SSPs are not exhaustively detailed in quantitative terms. This means that integrated assessment modelling (IAM) teams can interpret the SSPs in different ways, leading to a range of outcomes in energy, land use and therefore radiative forcing. This range indicates baseline uncertainty in these reference scenarios without climate-motivated policy (fig.7; van Vuuren et al., 2013).

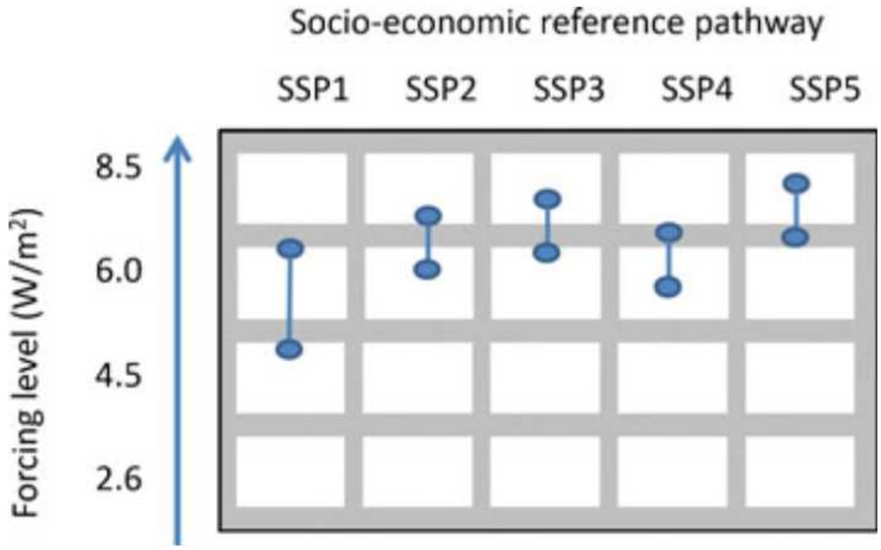

Fig. 7 – Two dimensional scenario matrix architecture without the climate policy dimension. Lines indicate uncertainty in forcing outcome due to different possible interpretations of the SSPs. Figure from van Vuuren et al. (2013)

b) *As a framework for systematically exploring scenarios*

Mitigation studies investigate the climate policy assumptions needed to access lower forcing levels (RCPs) with a given SSP (fig. 8a). While not shown in fig 8a, inclusion of the third (SPA) dimension would provide a sloping surface in the scenario space that means lower forcing levels can be accessed for a given SSP with increasing climate policy potency. Working down a column in this manner (fig. 8a) also allows impacts, adaptation and vulnerability (IAV) modellers to evaluate the impact and adaptation consequences of different degrees of climate change for a given SSP (van Vuuren et al., 2013). Alternatively, IAV communities may study how the impacts of climate change and the options for adaptation vary for the same forcing level (RCP) across different socio-economic pathways (fig. 8b; van Vuuren et al., 2013)

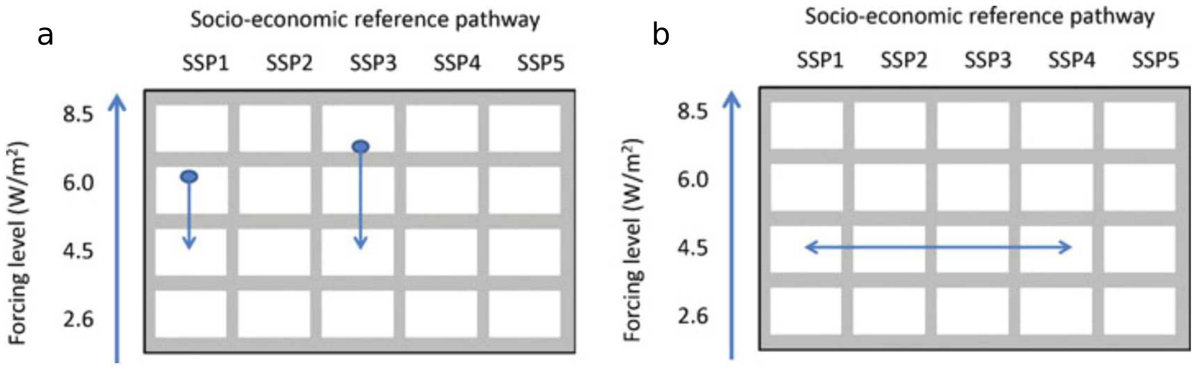

Fig. 8 – Matrix architecture provides a framework for research questions. A) Moving to lower RCPs with a given reference SSP. B) Moving across SSPs with a given forcing level. Figure from van Vuuren et al. (2013)

c) *For the characterisation of costs for mitigation, adaptation and costs of residual impacts – the role of different socio-economic developments and climate policies*

By holding an SSP constant, the two-dimensional relationship between forcing levels and policy assumptions can be explored. Fig. 9 shows how this can be used as a basis to explore the costs of sufficient mitigation to achieve a given RCP associate with three different types of policy coordination (cooperative and with different degrees of fragmentation) for SSP1 and SSP2 (figs. 9a and 9b respectively).

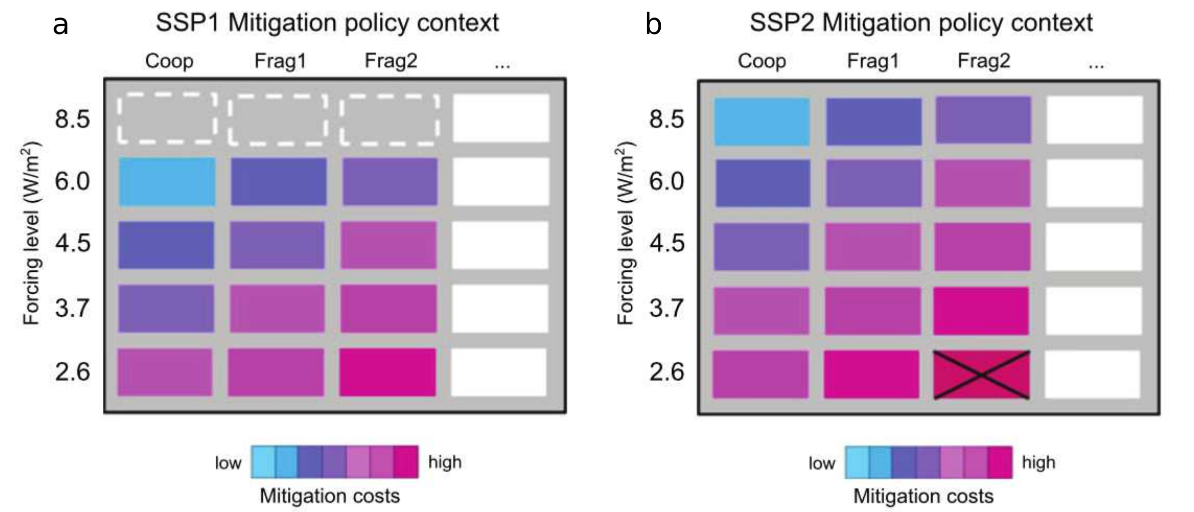

Fig. 9 –The SSP dimension is held constant. Three different types of policy action involving cooperative (Coop) and different degrees of fragmented participation (Frag1 and Frag2) are compared in terms of the necessary costs associated with mitigation measures to achieve the given forcing levels. A) SSP1, low challenges to adaptation and mitigation. RCP8.5 is deemed incompatible with SSP1, because an SSP1 society would not follow such a carbon-intensive future. B) SSP2, the intermediate pathway. RCP2.6 is considered unachievable with any level of expenditure with a highly fragmented participation in climate policy. Figure from Kriegler et al. (2014)

Similarly, the framework can be used to explore the costs of different stringencies of adaptation policies and the residual impacts of climate change in scenarios based on different SSPs and forcing levels (figs. 10a and 10b).

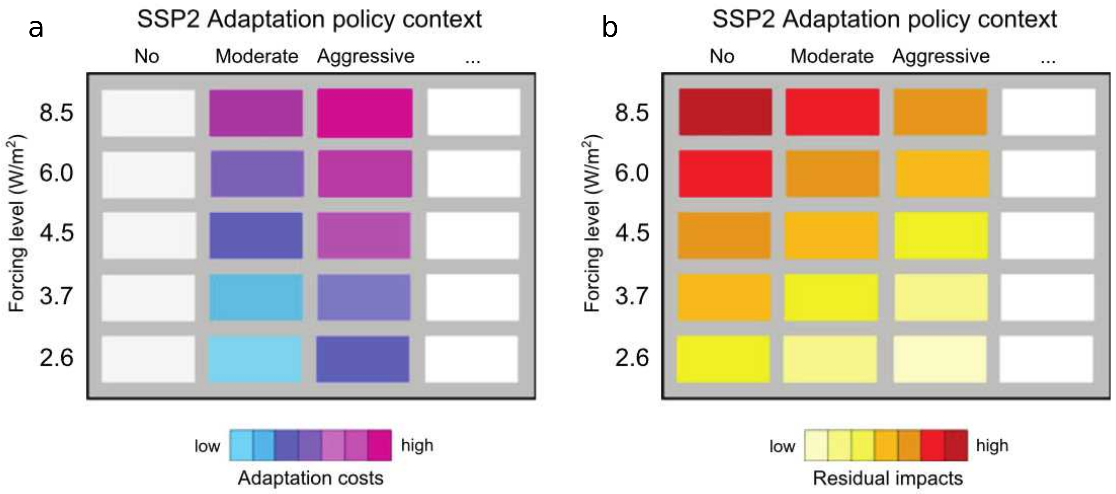

Fig. 10 – Exploring the costs of adaptation policies and resulting residual impacts under certain scenarios arising from combinations of RCPs and SSPs (in this case, SSP2). A) adaptation costs with SSP2, different forcing levels and different levels of adaptation policy. B) Residual impacts. Note how these are highest for the most severe climate change, weaker adaptation scenarios. Figure from Kriegler et al. (2014)

Alternatively, the costs associated with implementing mitigation measures to achieve a certain RCP in different SSPs can be explored (fig.11a) or the adaptation and residual impact costs in each of those scenarios (fig. 11b).

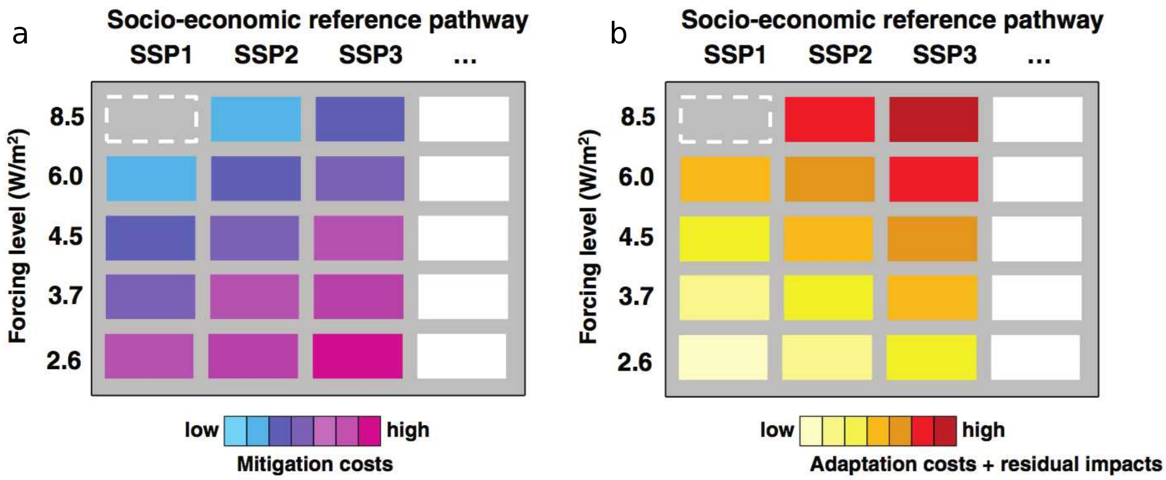

Fig. 11 – A) Mitigation costs required to achieve certain forcing levels under different SSPs. B) Adaptation costs and residual impacts associated with different levels of forcing and the SSPs. Note that SSP1 is deemed incompatible with RCP8.5; an SSP1 society experiences low challenges to mitigation and therefore the probability of following this high emissions pathway is negligible. Figure from van Vuuren et al. (2013)