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A new scenario framework for climate change research: the concept of shared climate policy assumptions

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Abstract The new scenario framework facilitates the coupling of multiple socioeconomic reference pathways with climate model products using the representative concentration pathways. This will allow for improved assessment of climate impacts, adaptation and mitigation. Assumptions about climate policy play a major role in linking socioeconomic futures with forcing and climate outcomes. The paper presents the concept of shared climate policy assumptions as an important element of the new scenario framework. Shared climate policy assumptions capture key policy attributes such as the goals, instruments and obstacles of mitigation and adaptation measures, and introduce an important additional dimension to

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the scenario matrix architecture. They can be used to improve the comparability of scenarios in the scenario matrix. Shared climate policy assumptions should be designed to be policy relevant, and as a set to be broad enough to allow a comprehensive exploration of the climate change scenario space.

Abbreviations

IAM	Integrated assessment modeling
IAV	Impacts, adaptation, and vulnerability
RCP	Representative concentration pathway
SPA	Shared climate policy assumption
SSP	Shared socioeconomic reference pathway

1 Introduction

Scenarios about future socioeconomic and climate developments are used to study the scope and implications of climate change and responses to it (Nakicenovic et al. 2000; Moss et al. 2010; Kriegler et al. 2012; van Vuuren et al. 2012). Over the past years, the research community has pursued a vision for an improved scenario-based climate change assessment process (Moss et al. 2008). An important feature of that vision was the ability to explore a greater variety of socioeconomic development pathways for emissions mitigation and climate impacts and adaptation. To that end Representative Concentration Pathways (RCPs) were created (van Vuuren et al. 2011) as a preliminary step to facilitate the creation of a set of climate model calculations, which in principle could be matched with new scenarios sharing the same climate forcing. To link possible socioeconomic development futures with a number of different climate outcomes, assumptions about mitigation and adaptation climate policies are needed. In this way, the analysis of climate policy is deeply embedded in a scenario-based assessment of climate change.

It is a fundamental question how scenarios can best be used to analyze policy (Morgan and Keith 2008). In general, this will depend on the policy context. If the decision problem can be broken down to the options and contingencies a specific decision maker is confronted with, scenarios may be developed for each alternative course of action and conceivable state of the world in close interaction with the decision makers (e.g. Parson 2008). Examples include for instance scenarios developed to inform specific business or planning decisions. Climate policy analysis is different in that it relates to a wider set of questions, ranging from regional adaptation plans for the near term to short- and long term climate mitigation strategies as, e.g., considered in international climate policy negotiations. Climate change scenarios are therefore often targeted to intermediate users, such as researchers who use scenarios as inputs into their work (Moss et al. 2008). These scenarios have to be specified in a way that retains their flexibility to be applied to different climate policy contexts. There is sometimes a perceived tension between scenarios directed to research vs. decision support. However, they are rather complementary in nature. Scenarios directed to research should be applicable as analytic tools to develop decision support scenarios in a specific context.

This paper takes up the question of scenario based policy analysis in the context of the new scenario framework. The framework is introduced in a series of four papers in this special issue (Ebi et al. 2014; van Vuuren et al. 2014; O'Neill et al. 2014, are the other three).

The general approach is presented in van Vuuren et al. (2014). At its core is the concept of a scenario matrix that combines so-called shared socioeconomic reference pathways (SSPs) with climate forcing outcomes as described by the representative concentration pathways (RCPs, van Vuuren et al. 2011). The RCPs reach different levels of climate forcing in the year 2100 and thus can serve as proxy for climate targets.[1] The SSPs are introduced in O'Neill et al. (2014) and aim to characterize socioeconomic challenges to mitigation and adaptation in a reference case without explicit climate policies and without consideration of climate change impacts. Per definition, the SSPs provide the constituents of a reference scenario that can serve as a counterfactual to evaluate the impact of climate policy. To allow their broad applicability they have to exclude any climate policy, but can include other policies that are not directly related to climate. In fact, to be useful for climate policy analysis they should include all those policies controlled by non-climate objectives that will either have a substantial impact on climate policy related outcomes or be substantially impacted by climate policy itself.

The cells of the scenario matrix are defined by combinations of distinct SSPs and climate forcing outcomes (as characterized by the RCPs). Some of these cells at the higher end of the forcing range, e.g. for the two RCPs attaining 6 and 8.5 W/m2 by the end of the century, may be populated by reference scenarios that project socioeconomic developments and emissions in the absence of climate policy and are based purely on the SSPs, although the extent and pattern of climate change could affect development pathways such that the SSPs may need to be modified when creating a scenario. Climate policies will be needed to an increasing degree to reach the lower part of the RCP range, particularly for 2.6 and 4.5 W/m2. The scenarios created in these matrix cells will therefore draw on SSPs, but also make assumptions about climate policy including mitigation and adaptation measures. The impact of such policy scenarios could then be analysed by comparing it with the reference scenario for a given SSP (within a column of the matrix; see van Vuuren et al. 2014, for further discussion).

This is the entry point of our analysis. We ask the question how the formulation of climate policy scenarios could be framed to enhance their applicability to the scenario framework, in particular concerning their introduction into the RCP-SSP matrix. We note that our discussion applies entirely to the use of climate policy scenarios in this framework, not to climate policy scenarios in general. There always has been, and always should be a large variety of climate policy scenario analyses to cater to the widely different decision contexts in the area of climate change.

We start from two observations. Firstly, the RCPs, as a measure of the anthropogenic forcing of the climate system, may characterize the target of mitigation action, but not the type and structure of climate policy interventions including mitigation and adaptation measures. Secondly, any set of climate policy assumptions will have strong implications for the outcome of the scenario analysis in the proposed RCP-SSP framework. For example, the assumption of the time by when a long term climate target is adopted globally will strongly influence the ability to reach this target in addition to the challenges to mitigation characterized in the SSPs. Likewise, the existence of a global adaptation fund and international insurance mechanisms against climate change impacts will affect the ability to implement adaptation measures in addition to the challenges to adaption in the SSPs. We therefore ask the question how the SSP

[1] We need to distinguish between the four RCPs created for climate model simulations (van Vuuren et al. 2011) and climate forcing used more broadly to characterize the rows of the scenario matrix (van Vuuren et al. 2014). Since the four RCPs establish the direct link to the climate model results, they are obviously prime candidates to define the rows of the matrix. However, additional rows for intermediate forcing levels such as 3.7 W/m2 could be added, or the forcing outcome could be described more broadly by the 2100 level of the RCPs rather than the entire pathway. A forcing pathway may deviate from an RCP in some aspect and still be associated with the matrix row defined by the RCP. Such forcing pathways have been called RCP replications.

and forcing (RCP) dimensions should be augmented by Shared Climate Policy Assumptions (SPAs) to better incorporate the climate policy dimension within the scenario framework. The idea that policy assumptions may be shared between studies should not be confused with a prescription that all countries should take the same level of action, or should act under internationally co-ordinated regimes. To this end, we note that assumptions are not recommendations, and that the usefulness of making assumptions will depend on how broad a range of plausible climate policy formulations is assessed. This may include, at a minimum, climate policy assumptions that describe regionally differentiated and globally harmonized approaches.

Section 2 will discuss the definition and scope of SPAs, while Section 3 conceptualizes their quantitative and qualitative elements. Section 4 turns to the difficult question of the dividing line and the inter-dependence between SPAs and SSPs. Section 5 provides examples of how SPAs can be integrated as a third dimension in the scenario matrix architecture. Section 6 concludes that it can be useful to characterize the key dimensions of climate policy assumptions in SPAs much in the same way as socioeconomic reference assumptions are summarized in the SSPs.

2 Defining shared climate policy assumptions

Climate policies can be characterized in terms of their attributes, such as the stringency of policy targets, the set of climate policy instruments employed to achieve the targets , and the time and place in which climate policy instruments are deployed. Following a proposal by Kriegler et al. (2012), we define Shared Climate Policy Assumptions as capturing key characteristics of mitigation and adaptation policies up to the global and century scale. The latter requirement emerges from the fact that SPAs should relate to the global scenario framework. At the same time they should be flexible enough to allow for regional differentiation of policies.

Concretely, SPAs should describe three attributes of climate policies (Kriegler et al. 2012). The first attribute is the global (collection of) ***"climate policy goals"*** such as emissions reductions targets, or different levels of ambition in limiting residual climate damages, e.g. in terms of development indicators that should not be jeopardized by climate change. However, there is a clear overlap of mitigation policy goals with the forcing (RCP) dimension of the scenario matrix, and of adaptation policy goals linked to achieving sustainable development and other societal goals described in the SSPs. RCP forcing levels can be used to directly describe long term mitigation targets (although not how to achieve those targets), and in any case have strong implications for the admissible global outcome of regional emissions reduction targets.

Thus, we have to distinguish two types of SPAs: a full SPA that includes all mitigation and adaptation policy targets, and thus embeds the forcing (RCP) dimension and possibly aspects of an SSP in it. And a reduced SPA that excludes the mitigation policy goals, at least as far as they relate to emissions reductions and global concentration and forcing outcomes, and the adaptation policy goals as far as they relate to development goals, and therefore is orthogonal to both the forcing (RCP) and the SSP axis of the matrix framework. Thus, the reduced SPA has to be used if variations of policy assumptions for a given RCP-SSP combination are to be explored. In this way, it adds a third axis to the scenario matrix. Both concepts—reduced and full SPA—can be entertained simultaneously. A full SPA may simply be the combination of a reduced SPA and an RCP forcing level. Or, if the mitigation targets are to be specified in terms of regional emissions reductions commitments, the RCP forcing level would determine the global cumulative amount of permitted emissions (and possibly some properties of the global emissions pathway), while the reduced SPA is free to include any distribution of these emissions permits across regions that adds up to the global total. Similarly, for adaptation policy goals, a full SPA would embed SSPs elements, such as development goals that are relevant for adaptation policies, while a reduced SPA would focus purely on the adaptation policy aspect. We note that this differentiation of full and reduced SPAs to ensure orthogonality of the SPA, SSP, and forcing (RCP) axes goes beyond what was proposed in Kriegler et al. (2012).

Second, the shared climate policy assumption should describe the characteristics of the global (collection of) **"*policy regimes and measures*"** introduced to reach the policy goals- On the mitigation side, such policy measures could be globally harmonized or regionally differentiated carbon taxes, an international emissions trading scheme with a particular burden sharing mechanism, a mix of different policy instruments ranging from emissions pricing to low carbon technology subsidies to regulatory policies, or a mix of different approaches in different sectors, e.g. including transport policies and schemes to protect tropical forest. SPAs may also relate to mitigation policy dimensions that are often not considered by model studies, but elsewhere in the literature. An example is how particular policies would be financed in practice (Clapp et al. 2012; Winkler et al. 2009). On the adaptation side, the SPA package may include, for example, the type of adaptation measures that are implemented (e.g. more efficient irrigation techniques or water recycling technologies) and the availability of various amounts of international support for adaptation in developing countries.

Third, a shared climate policy assumption should include the **"*implementation limits and obstacles*"** to the extent they are considered and are not part of an SSP. Those obstacles could be specified in terms of the exclusion of several policy options for some regions and sectors where they do not appear to be feasible. Such conditions could evolve over time such that initial limits might dissipate or intensify. For example, several land pools may be excluded from carbon pricing due to practical constraints of implementing such a pricing policy. Or a group of regions may be assumed to remain outside an international climate policy regime until some point in time. Likewise, adaptation effectiveness may differ in a model where behavioral biases in risk perceptions are accounted for, or where political economy or enforcement constraints makes it impossible to implement some policies (e.g., land-use regulations aiming at reducing disaster losses are difficult to implement in areas without official land tenure such as informal settlements).

Care needs to be taken to separate implementation limits and obstacles that are attributes of a SPA, and climate policy obstacles that are inherent in the socioeconomic reference environment described in an SSP. The latter can include market distortions, e.g. in energy and labor markets. Babiker and Eckaus (2007) and Guivarch et al. (2011) show that taking into account unemployment and friction in labor market adjustments can change in a significant way the assessment of mitigation costs. In developing countries in particular, existing economic distortions cannot be disregarded in the design of climate policies. The high level of unemployment (often over 25 %), the large share of the informal economy, and the difficulty to enforce regulation (e.g., in terms of land-use planning) and raise taxes create specific difficulties for climate policy. To the extent that such elements are considered, they will be part of an SSP rather than a reduced SPA. However, they could be added to a full SPA that aims to provide a complete picture on the three attributes of climate policy, i.e. goals, instruments, and obstacles.

The formulation of SPAs on a global and century scale can become complex. However, the goal of SPAs should not be to describe the climate policy landscape in every conceivable detail, but rather to summarize and make explicit the central policy assumptions that have to be made anyway by individual studies to produce climate policy scenarios. Seen through this lens, SPAs have been used for quite some time, for example, in integrated assessment model inter-comparison studies (e.g. Clarke et al. 2009; Riahi et al. 2014; Kriegler et al. 2014a) that needed to harmonize their climate policy assumptions in order to make results comparable. It is more and more recognized that such harmonization does not only involve the specification of a long term climate target as would be captured by the RCPs, but also, e.g., the basket of greenhouse gases and sectors to become subject to emissions pricing, the degree of global cooperation and the degree of overshoot of long term targets (Blanford et al. 2014).

A controlled variation of key climate policy assumptions, but not of all the details, will be required to make the scenario matrix approach fully operational. Knowledge about what type of SPAs have been used in modeling will be required to make appropriate comparisons across model analyses or other studies that explore a given combination of SSP and radiative forcing target (RCP). For instance, mitigation cost assessments by two models cannot be compared directly, if these two models make different assumptions on practical obstacles to policy implementation (e.g., if one model assumes a globally integrated carbon market and the other a regionally fragmented mitigation regime). Furthermore, the choice of SPAs will interact with the socioeconomic challenges to mitigation and adaptation that are engrained in the SSPs (O'Neill et al. 2014). For example, whether or not global coverage of emissions reductions can be achieved will affect the ability to reach a prescribed RCP forcing level. Likewise, whether or not a global adaptation fund is put in place will affect the ability of individual regions to adapt to climate change.

3 Elements of shared climate policy assumptions

Shared Climate Policy Assumptions can contain qualitative and quantitative information. The qualitative information consists of a **narrative** that describes the world of climate policies and their evolution over time and across space (Hallegatte et al. 2011). A key characteristic of mitigation policies is the number of countries that participate in an international climate policy regime over time and the stringency of their commitments and actions. IAM studies often distinguish a benchmark case of fully cooperative action starting immediately with more plausible policy scenarios that include regionally and sectorally fragmented climate policies, staged accession to a global climate regime, and non-participation (Clarke et al. 2009; Blanford et al. 2014; Kriegler et al. 2014b; Luderer et al. 2014). Thus, the SPA narrative should include information on the different timing of participation of regions and nations in emissions mitigation regimes, as well as being explicit whether mitigation stringency is globally uniform or differentiated across regions and countries. It could also contain information about the nature of climate policies—e.g., preferences for fiscal as opposed to regulatory policies, differences in the nature of policies to mitigate fossil fuel and land-use change emissions, and emphasis on behavioral changes, efficiency and demand-side measures vs focusing mitigation more on upstream technology solutions for energy supply. In addition, SPA narratives could take into account information about the constraints and obstacles for mitigation policy.

Key qualitative information on adaptation policies includes institutional policies that are implemented to support adaptation, such as the implementation of a technology transfer agreement at the international scale; the quality of adaptation governance processes (e.g., corruption, capture by interest groups); and the effectiveness of policy implementation (e.g., enforcement of building norms and land-use regulations). Table 1 presents an illustrative example of key components of such narratives, and how they can be combined to a limited number of SPAs that cover a fairly wide range of different climate policy futures.

SPAs will in general also contain quantitative information. As far as full SPAs are concerned, the long term mitigation target as determined by the long term forcing in an RCP will be a central part of this information. In principle, the target could be specified in a

Table 1 Illustrative example of a set of reduced SPAs (columns) defined by a collection of policy attributes (rows) SPAs. Those SPAs can be combined with an RCP forcing level and an SSP, although not all combinations can be expected to be consistent and yield a feasible scenario. In addition, it may be useful to consider a "no new policy" SPA that only contains existing climate policies until their time of expiration, assuming no new climate policies thereafter

Policy attribute	Reference policy	Cooperation & moderate adaptation	Middle road & aggressive adaptation	Fragmentation & moderate adaptation
Mitigation: Level of global cooperation (e.g. measured in terms of average share of emissions under a global climate target over some period)	Low	High	Medium	Low
Mitigation: Start of global cooperation (e.g. the time the first group of countries adopts a global target or an international carbon tax)	Never	Early	Mid Term	Late
Mitigation: Sectoral coverage	Focus on electricity and industry sectors. No significant inclusion of land use based mitigation options.	Carbon pricing on land. Full coverage of energy supply and end use sectors.	Forest protection and bioenergy constraints. Energy supply, transport and industry covered.	Limited forest protection, no limitation on bioenergy use. Electricity and industry covered.
Adaptation: Capacity building (e.g. measured in terms of the size of a global adaptation fund)	Small	Moderate	Large	Moderate
Adaptation: International insurance (e.g. measured in terms of the amount of climate impact insurance available between countries)	Only via international markets, with limited access for some countries	Insurance available for least developed countries	Global insurance provided	Only via international markets, with limited access for many countries

number of ways, ranging from a global temperature target, to a climate forcing target to a cumulative emissions budget for the entire world. It may also include some constraints on the pathway of climate forcing or global emissions. The RCPs will be a determining factor for globally aggregate descriptors of mitigation effort even if no global mitigation target is assumed. For example, they will strongly influence (together with the choice of SSP) the global level of a carbon tax path that could be assumed instead of a target (Calvin et al. 2012). Quantitative information that would be part of a reduced SPA, and thus would need to be complementary to information constrained by the RCPs can include, e.g., the allocation of emissions permits to different regions in terms of shares of global emissions (Tavoni et al. 2014), carbon price differentials between regions, sectors and land pools, a timetable for staged accession to a global climate policy regime (Clarke et al. 2009), regional low carbon technology targets (Kriegler et al. 2014b), and land use related policies such as forest protection and bioenergy constraints (Calvin et al. 2014). Quantitative assumptions on adaptation policy can include, for example, adaptation targets such as protection against 100 year flood or drought events, timetables for implementing regional adaptation plans, and the size of an international adaptation fund that is set up to assist countries that are most affected by climate change.

In summary, the SPAs should contain information that is instructive to both the integrated assessment modeler trying to develop a climate mitigation scenario, and an IAV researcher trying to analyse the vulnerability to climate change, the costs and benefit of adaptation measures and the residual climate impacts. The level of detail to which it is useful to specify information in the SPAs will depend on the application. Obviously, SPAs at the global and century scale have to be very generic by construction, since a detailed formulation of the global climate policy landscape in 2050 would carry little meaning. As for the case of the SSPs, there is an inherent tension between establishing comparability of different studies and comprehensive coverage of plausible SPAs (compare O'Neill et al. 2014). It may be useful to distinguish between basic SPAs that only include high level information on the scope of mitigation and adaptation actions and thus can summarize a larger set of climate policy studies, and extended SPAs that allow to better control climate policy assumptions as for example adopted in IAM comparison projects. Furthermore, the connection between global studies and mitigation and adaptation analysis conducted at the national level needs further attention. Global SPAs should be flexible enough to be adapted and changed when applied to more short-term and more local/national analysis, much in the same way as global SSPs should allow their adaptation to studies on a local/national level. National SPAs could, for example, be taken up in SPA extensions. However, a set of basic SPAs on the global level will be most useful if it is limited in number, generic in character and broad enough to allow a comprehensive exploration of the climate change scenario space.

4 The relationship between SPAs and SSPs

As discussed above, climate policy assumptions will not be included in SSPs by their definition in terms of socioeconomic reference assumptions. Thus, assumptions about climate policies, even if they correspond to currently planned legislation, should always be part of an SPA rather than an SSP. The dividing line between assumptions on climate policies to be included in SPAs and broader development policies to be included in SSPs will be difficult to draw in many cases. In general it is the motivation for the policy intervention and not the policy itself that determines whether the policy is a climate policy or a policy directed toward another end. As a consequence a policy may be included as a non-climate policy in the SSP, but tightening of the policy in support of greenhouse emissions mitigation, for example, could be included in the SPA. A renewable energy portfolio standard, for example could occur in a reference scenario in support of improved energy security, and a more stringent implementation might be included in an SPA. In the end the test is, would the policy and its stringency be expected to be enacted in the reference, no-climate-policy scenario? If the answer is yes, it belongs in the SSP. To the extent that the policy is deployed and/or tightened only in the mitigation scenario, it belongs in the SPA.

For example, any policy that directly constrains or taxes the emissions of greenhouse gases falls into a SPA. The same holds for any policy that directly addresses adaptation to climate change such as the implementation of an international adaptation fund. In contrast, most development policies such as improving energy access, urban planning, infrastructure, health services, and education are motivated in their own right, and thus are not climate policies. Those policies are part of the socioeconomic reference scenario, and their outline should be included in the SSPs. Such policies may, of course, affect climate policies, or be affected by them, which reinforces the case for their inclusion in SSPs. Care must be taken when combining SPAs with SSPs to ensure consistency of the full policy package (see below). For example, development policy assumptions in the SSPs may have to be adjusted when being combined with an SPA. However, this also holds true for other variables in the SSPs, such as land and energy use patterns that will be affected by climate policy.

There are also borderline cases due to the fact that policies are often motivated by multiple objectives (Linnér et al. 2012; Winkler et al. 2008). Is a renewable portfolio standard motivated by concerns about climate change or energy security or both? Does increased disaster preparedness stem from a concern about the increased frequency or magnitude of such disasters in a changing climate, or does it stem from the objective to decrease the vulnerability of the society to present climate variability? Such cases cannot fully be decided, and one may have to resort to ad hoc judgments on a case-by-case basis. The main point is that the relevant policy assumptions underlying the socioeconomic reference and climate policy scenarios are clearly allocated to either an SSP or a SPA. A clear separation of policies with respect to the climate and non-climate objectives in the SSPs and SPAs will make the framework also useful for the assessment of potential synergies and tradeoff between climate and other non-climate policies (McCollum et al. 2011).

Another important question is how to deal with climate policies and measures that are already implemented and affect the socioeconomic development on a larger scale. The price on greenhouse gas emissions in Europe, imposed directly via the European Emissions Trading System (EU ETS), or implicitly via sectoral measures aiming to reach the targets under the Kyoto Protocol, are a case in point. If such implemented climate policy measures are excluded from the socioeconomic reference scenario, it would have already diverged from reality. In order to avoid this, existing climate policies may be collected in a minimal “existing policy” SPA that can be combined with an SSP when developing the reference scenario. Seen in this way, any socioeconomic scenario, including the reference case, would be based on some SSP and SPA. Only a counterfactual no climate policy scenario would not require the adoption of a SPA, or, put differently, adopt an empty SPA.

The idea of a minimal “existing policy” SPA immediately raises the question of what is an existing climate policy: measures in effect like the EU ETS; or a policy foreseeing future measures that is coded into law like the EU Climate and Energy Package? And how should such policies be projected into the future in a policy reference case defined as continuation of current levels of ambition (Blanford et al. 2014; Kriegler et al. 2014b, Luderer et al. 2014)? These questions will need to be further addressed during the construction and testing of SSPs and SPAs, and their use in the development of socioeconomic scenarios. They are closely related to the long-standing discussion in many fields and applications of what should count as the baseline or reference case, against which actual policy proposals are measured. SPAs provide the flexibility to include different interpretations of “baseline” in the analysis.

When combining SSPs and SPAs to derive a socioeconomic climate policy scenario, care needs to be taken that their combination is consistent. First, SSPs will contain reference assumptions that are affected by climate policies, and those would need to be adjusted to take into account the information in the SPA. Second, some reference assumptions in an SSP, e.g. development policies, will have implications for climate policy, and consistency between a SSP and a SPA would need to be ensured. For example, a narrative describing a regionalized development in a fragmented world can hardly be paired with the assumption of a global carbon market. Likewise, implementation obstacles, e.g. in terms of land pools that can or cannot become subject to carbon pricing, can be more or less consistent with different SSP. It therefore will be the case that not all SPAs can be combined consistently with all SSPs.[2] It is important that at least one SPA be developed so as to be consistent with each SSP.

5 Integrating SPAs into the scenario matrix architecture

The explicit introduction of a climate policy dimension as captured in the SPAs offers the flexibility to explore adaptation and mitigation policies for different combinations of SSP, RCP and reduced SPAs. For example, Fig. 1 shows the combination of RCPs with reduced SPAs describing different types of mitigation policies for a given SSP. Mitigation costs do not only vary with the stringency of mitigation targets (RCP levels), but also with the degree of global cooperation on mitigation policy. See also the conceptualization of mitigation SPAs in a scenario matrix setting in Knopf et al. (2011; Figure 6).

The adaptation policy assumptions can also be varied across SPAs. Figure 2 shows the example of three different reduced SPAs with no, moderate and aggressive adaptation policies. In general, a SPA will include a consistent set of assumptions on mitigation and adaptation policies specifying, e.g., the degree of coordination of regional and sectoral mitigation efforts and the aggressiveness of adaptation measures. Combining the information in Figs. 1 and 2 will allow to compare total climate policy costs with residual climate damages for a given combination of SSP, RCP and SPA, and also will allow the exploration of interactions of adaptation and mitigation policies because the extent of efforts required to adapt later in the century will depend on mitigation policies implemented in the near term

As discussed in O’Neill et al. (2014), shared socioeconomic reference pathways should be chosen in a way to cover different levels of socioeconomic challenges to mitigation and adaptation. Here we want to point out that SPAs will play an important role in translating those challenges into costs, benefits and obstacles to climate policy. For example, a SPA that foresees a group of countries that never adopt mitigation policies throughout the 21st century, can imply a greater difficulty to reach global mitigation targets than a SPA with global participation in a climate mitigation regime for the same SSP with given challenges to mitigation. Similarly, a SPA that restricts adaptation to domestic action will have a more limited scope for adaptation action than a SPA that allows for international pooling of adaptation resources. In many cases, the challenges to mitigation and adaptation in SSPs and the obstacles to mitigation and adaptation in SPAs will be correlated by the requirement that SPAs need to be consistent with

[2] On the other hand, it will sometimes prove useful to compare the effects of a consistent SPA with realistic policy representation with an “idealized policy” SPA that may not be fully consistent with the SSP in order to gain analytical insights.

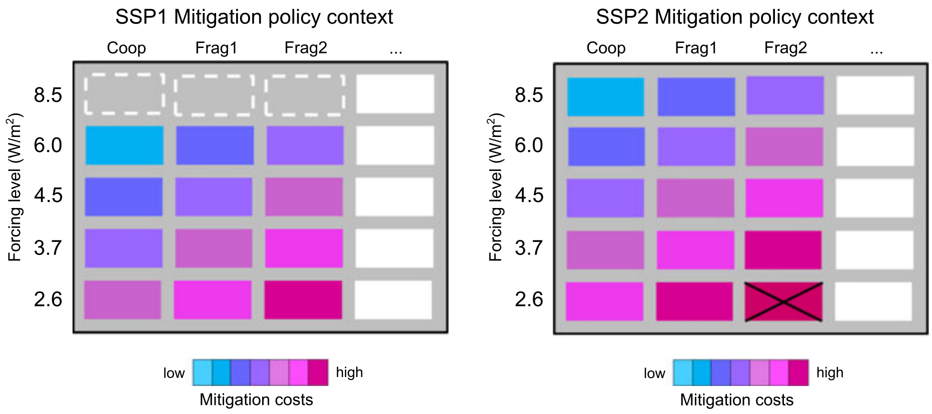

Fig. 1 A policy axis can be added to the matrix architecture to explore how the costs of mitigation policy depend on assumptions regarding the form of mitigation action. Here, the costs assuming cooperative action (Coop) are compared to policies with different degrees of fragmented participation (Frag1 and Frag2) for SSP1 and SSP2 (see O'Neill et al. for a description of the SSP space). Some targets cannot be achieved with fragmented participation (indicated by the cross)

the underlying SSPs (see above). For example, an SSP describing a fragmented world with regional blocks neutralizing each other can hardly give rise to global cooperative action on climate change, and therefore would exclude SPAs characterized by a large degree of international cooperation. In this situation, the challenges to mitigation and adaptation in the SSP would be augmented by the obstacles from the non-cooperative nature of the SPA.

6 Summary and conclusions

We presented the concept of shared climate policy assumptions (SPAs) as an important element of the new scenario framework for climate change analysis. SPAs are the glue that

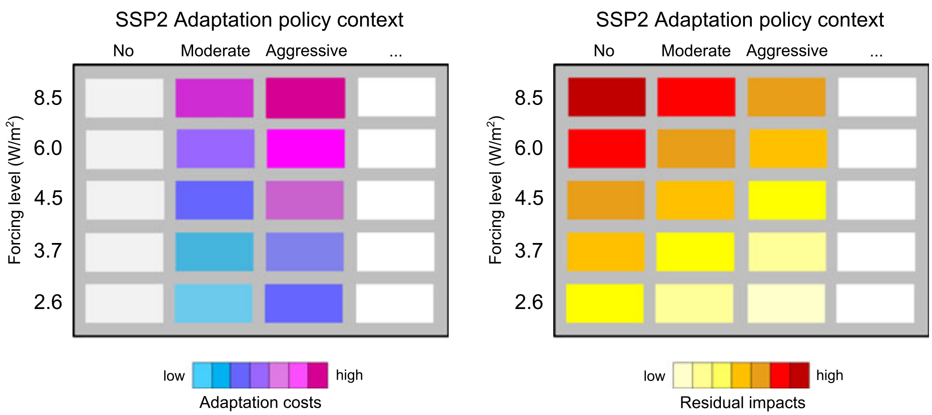

Fig. 2 The type of adaptation policy can also be explored within the matrix architecture. Here, adaptation policy is varied from no adaption to moderate to aggressive adaptation. The matrix allows for the comparison of the costs and benefits of the adaptation policy for a given SSP, for example SSP2. The shading for climate policy adaptation costs and residual climate impacts is provided for illustrative purposes only

allows the variety of alternative socioeconomic evolutionary paths to be coupled with the library of climate model simulations that were created using the RCPs. SPAs capture key climate policy attributes such as targets, instruments and obstacles. In their reduced form, SPAs are restricted to information that is neither specified in the socioeconomic reference pathways (SSPs), nor in the RCPs which largely determine the global outcome of mitigation action and the extent of adaptation required. Thus, reduced SPAs add a third dimension to the scenario matrix architecture of RCPs and SSPs. We demonstrated how the scenario matrix can be explored along the dimensions of SPAs. For a given combination of SSP and RCP, both the climate policy costs, including adaptation and mitigation, as well as the residual climate damages will vary with the climate policy assumptions. Of course, elements other than costs and benefits are needed for a full policy appraisal (e.g. regional context, institutional capacity, co-benefits and risk trade-offs; McCollum et al. 2011), and those may be explored on the basis of SPAs as well. In summary, SPAs can contribute to transparent and consistent assumptions about policies. A meaningful set of generic shared climate policy assumptions will be needed to group individual climate policy analyses and facilitate their comparison.

SPAs should include assumptions about both mitigation and adaptation policies. Key assumptions relate, inter alia, to the degree of global cooperative action on mitigation and the international pooling of adaptation resources. SPAs will typically comprise quantitative information, e.g. relating to the regional distribution of mitigation effort, and qualitative information in terms of a narrative or storyline, e.g. relating to the degree of international cooperation. The appropriate level of detail of SPAs will depend on the application. There is an inherent tension between sufficient detail to facilitate comparison between climate policy studies and generality to group them into broad classes of SPAs.

SPAs should only contain information about climate policies, while other policies under consideration should become part of SSPs. The motivation of a policy may be used to determine whether it belongs in the SSP or the SPA. If a policy would be deployed in the absence of climate change, then it belongs in the SSP. If a policy is deployed and/or tightened solely in response to climate change, then it belongs in the SPA, but only that portion that is motivated solely by climate change. We acknowledge that for some multi-objective policies a clear dividing line does not always exist. Some decisions will have to be made on a case by case basis depending on the application context. However, these questions are part and parcel of any climate policy analysis, and not restricted to the use of SPAs.

While SPAs are complementary to SSPs, the character of a socioeconomic reference pathway can constrain the choice of plausible climate policy assumptions. Not every combination of SPA and SSP will provide a consistent scenario. For example, a fragmented world will not be able to provide for full global cooperation on climate change. There should be at least one SPA that is consistent with each SSP. Socioeconomic challenges to mitigation and adaptation that are described by an SSP can be augmented by the choice of SPA. For example, if global cooperation is highly constrained in a given SPA, this will add to the challenges to mitigation and adaptation in the SSP.

We conclude that SPAs are an important concept to facilitate climate policy analysis in the new scenario framework. Their formulation and application will have to be further developed and tested, which may involve iteration between modelers, analysts and various stakeholders. If SPAs are designed to be broad enough to allow an exploration of the relevant climate policy space, their use will likely provide new insights into the implications of alternative policy designs for climate action.

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