Improving the relevance of the Shared Socioeconomic Pathways for sustainability science

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Non-technical summary

Sustainability scientists use scenarios to investigate what different futures might look like. Many sustainability assessments have used a set of scenarios that were developed for climate science. We argue that these scenarios are less than ideal for examining sustainable futures because many things important for sustainability are not included in the climate scenarios, for example different economic outcomes beyond growth, or human equity and justice. We need to develop scenarios specifically for sustainability science to help us explore the range of possible futures with different types of economic, social, and environmental outlooks.

Technical summary

Sustainability science is a discipline which is strongly concerned with exploring the achievement of sustainable futures. One way in which this is done is through scenarios. The Shared Socioeconomic Pathways (SSPs), developed for climate science, have been widely adopted by modellers to analyse sustainable futures. We question whether the SSPs are fit-for-purpose for examining sustainable transformative futures. We have identified six challenges and propose aligned opportunities synthesised from existing research. These challenges are: the need for a sustainability context in the scenario space; better representation of sustainability challenges in the driving forces which form the scenarios; narrowed scope of storylines due to coupling the scenarios to modelling; constraint of economic futures to growth-only options; the scenarios are not goal-seeking, nor do they consider deep uncertainty; and the scenarios are insufficiently diverse. The inclusion of different driving forces, degrowth scenarios, and a different scenario space, are some of the proposed improvements suggested. Addressing these challenges and rethinking the use of climate-SSPs should be a priority for the sustainability science community, considering how critical scenario-based research is for policy and practice.

Social media summary

Climate SSPs are being used for sustainability research. We present 6 challenges & opportunities for modification.

Introduction

In the 2010s, the climate change research community embarked upon a process to develop a new set of scenarios for use in integrated assessment modelling for climate futures. These scenarios were integrated with the scenarios of atmospheric emissions trajectories (Representative Concentration Pathways (RCPs); van Vuuren et al., 2011) and shared climate policy assumptions (SPAs; Kriegler et al., 2014) and were intended to represent socioeconomic and environmental change in the context of global challenges to climate adaptation and mitigation. This set of scenarios was called the Shared Socioeconomic Pathways (SSPs; O'Neill et al., 2017) and their use has had a significant impact on the Intergovernmental Panel on Climate Change (IPCC) reporting process (Pedersen et al., 2022) and on global change research more broadly (O'Neill et al., 2020). The SSPs have been adopted across global change research communities (including sustainability science). However, we argue that the SSPs have often been applied somewhat uncritically and without sufficient regard for their transferability. We question whether the SSPs are fit-for-purpose for examining sustainable transformative futures and have identified six challenges, with aligned opportunities synthesised from existing research.

The SSPs are a set of five global scenarios built from driving forces (or *elements* as described in O'Neill et al., (2017)), and the *scenario space* (Figure 1) which they occupy represents socioeconomic challenges for climate adaptation and climate mitigation. We use the term *scenario* here rather than *pathway* following the typology of McDowall and Eames (2006), where scenarios are defined as exploratory storylines built using the underlying drivers of change. These five scenarios are: SSP1 *Sustainability,* SSP2 *Middle of the Road,* SSP3 *Regional Rivalry,* SSP4 *Inequality,* and SSP5 *Fossil-fueled development.*

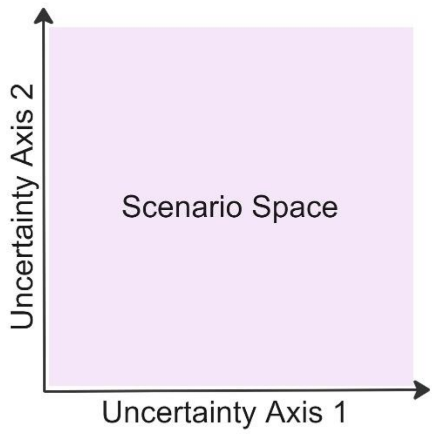

Figure 1: Generalised representation of a scenario space with two axes of uncertainty. These axes are *climate adaptation* and *climate mitigation* in the SSPs.

One of the key innovations of the SSP framework is that it was designed to have the flexibility to extend beyond its original use-case in climate change research (O'Neill et al., 2017). The SSPs have been extended to explore climate change challenges in various sectors including tourism (Hyytiäinen et al., 2022), agriculture (Lehtonen et al., 2021; Mitter et al., 2019), and water (Yao, Tramberend, Kabat, Hutjes, & Werners, 2017). Extending the SSPs through downscaling to national and regional scales was readily implemented by the research community, with examples of regional and sectoral SSPs in the USA (Absar & Preston, 2015), the Barents region (Nilsson et al., 2017), and west Africa (Palazzo et al., 2017). However, extending the SSPs to different contexts beyond climate change has not been undertaken so broadly or so thoughtfully – even though the SSPs as a scenario framework has the capability to do so (O'Neill et al., 2020). The scenarios working group examined the framework and application of SSPs in O'Neill et al., (2020) and concluded that modifications would be required to the existing SSP-RCP framework for sustainable development purposes. However, as at the most recent iteration of the SSP Literature database (Green et al., 2022), 67 papers since 2015 were found which use the SSPs in the context of the Sustainable Development Goals (SDGs), which is only a subset of sustainability science applications, indicating an increasing adoption of the SSPs beyond climate change research. The 2022 Scenarios Forum meeting report recognised that the

SSPs are “widely used through the climate and sustainability research communities” (van Ruijven et al., 2022, p. 11).

SSPs in sustainability science: challenges and opportunities

In sustainability science, scenarios are used for envisioning possible futures to assist with decision-making, both with and without quantitative modelling. For many of these scenarios, *transformative* change is required to achieve a sustainable future. Here, we follow the convention that *transformation* refers to systems-level change (i.e., economy, environment, and society interacting), while *transition* occurs at the sub-system level, e.g., energy sector transition (Patterson et al., 2017; Scoones et al., 2020). Understanding how to achieve and reach such transformation is one important purpose of scenarios, either in an exploratory fashion (using drivers to explore possible futures), or goal-oriented (achieved by backcasting; defining a desirable future and developing pathways to reach that future). A key concern is that the reference SSP scenarios are not fit-for-purpose for exploring sustainability transformation for several reasons, which we will outline below, and are summarised in Figure 2. Despite these challenges, we believe that the SSP framework has many positive aspects. The method of scenario narrative development allows for creativity. The scenario matrix architecture by which the SSPs can be cross-referenced with the RCPs and shared policy assumptions (SPAs) for modelling purposes is likewise well constructed. The framework is adaptable and opportunities to improve the relevance of the SSPs have been well explored in the literature. We are not advocating for the abandonment of the SSPs, but rather identifying challenges for their use in sustainability applications and synthesising opportunities that have been presented in other work.

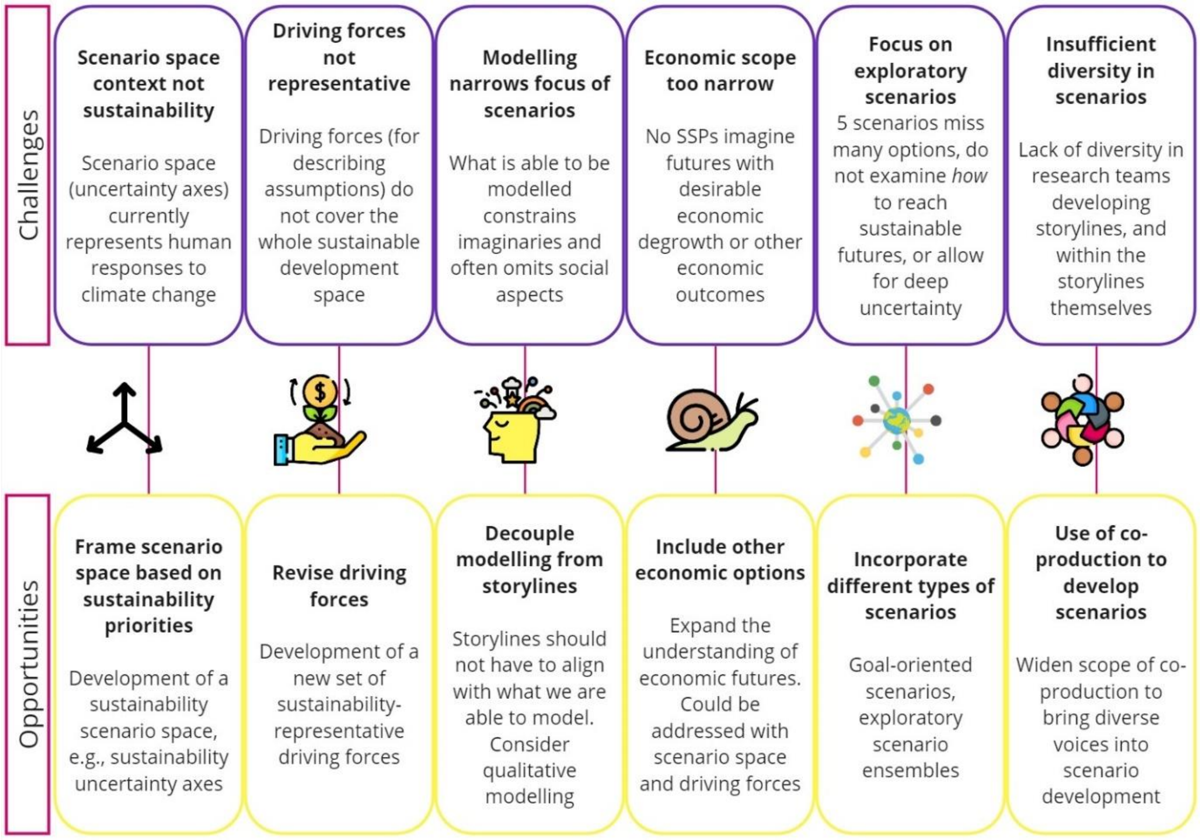

Figure 2: A summary of challenges and opportunities for the way forward. The top row of boxes summarise the six challenges outlined with respect to using the SSPs for sustainability science. The bottom row of boxes provides some opportunities for how to address these challenges. Icons from www.flaticon.com.

1. Scenario space context (uncertainty axes)

The first challenge is that the context, or scenario space and uncertainty axes (Figure 1) of the SSP scenario space does not capture fundamental components of sustainability, but instead reflects human responses to climate change. While climate change is one aspect of sustainability, there are many more dimensions that could and should be represented. Multiple studies have adopted the existing SSP scenarios in an SDG context to assess sustainability progress from local to global scales (Moallemi et al., 2022; Moyer & Hedden, 2020; e.g., Zimm, Sperling, & Busch, 2018). Rakovic et al., (2020) identified that using the climate change scenario space led to difficulties in mapping the driving forces to their bioeconomy context, and reflected that redefining the scenario space may have solved this problem. Liu et al., (2020) concluded that for achieving SDGs, the socioeconomic conditions have greater relevance than the climate settings of the scenarios. Limited research has focused on redesigning the SSPs to suit the sustainability context. This is a gap which was raised in a recent SSP review, suggesting further work toward a more comprehensive view of future scenarios to address the need for international sustainability goals such as the SDGs (O'Neill et al., 2020).

The opportunity here is to change the scenario space of SSPs intended for sustainability research. Some examples exist, from both inside and outside of climate research. SSPs have been reframed with axes of climate adaptation and mitigation in the context of Baltic Sea environmental problems, achieving both recontextualisation and downscaling together (Zandersen et al., 2019); and with axes representing the level of climate change that has occurred against regional collaboration (Talebian, Carlsen, Johnson, Volkholz, & Kwamboka, 2021). In the sustainability context, climate responses have been removed altogether and replaced with resource consumption, and inclusion and equity (Allen et al., 2019); or a more general sustainability reframing in which three axes represent the dimensions of sustainability (environment, society, economy; Szetey et al., 2021). One emergent scenario of this last space is a low-growth option, addressing another challenge identified below, and a suitably designed scenario space should seek to represent diverse economic futures.

2. Driving forces

The second challenge of the current approach to the use of SSPs in sustainability science is with respect to the set of driving forces (described as elements by O'Neill et al., (2017)) which are used to build storylines. As the existing driving forces are aligned with the climate change context, what occurs with an uncritical adoption of climate SSPs is that the conditions embedded in them are aligned with sustainability goals, whether they are suitable or not. This means that factors which are important for sustainability but missing from the SSPs such as the drivers of poverty (Rao, van Ruijven, Riahi, & Bosetti, 2017) or justice and equity (Zimm, Schinko, & Pachauri, 2022); interventions such as circular economy and economic degrowth (Wiedmann, Lenzen, Keyßer, & Steinberger, 2020); and governance, partnerships, and collective action (Matson, 2022), among others, are not included in storylines or modelling, and implicitly not considered an important or relevant outcome of sustainability transformation. Moallemi et al., (2022) used the SSP framework but noted this was for illustrative purposes only, as the SSPs do not necessarily include driving forces that would be required for global achievement of the SDGs. Soergel et al., (2021) recognised these limits in the SSPs and developed a sustainable development pathway for SDG assessment, but observed that even this pathway did not fully address the SDG space, modelling 65 of 232 indicators. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) found the SSPs insufficient for biodiversity modelling needs and instead developed the Nature Futures Framework for biodiversity-focused scenarios (Rosa et al., 2020). Because of this focus on human responses to climate change, the base driving forces in the SSPs have an emphasis on technological outcomes to enable economic growth, while social drivers critical to sustainability such as human equity and justice are underrepresented (Hickel et al., 2021). In order achieve just transformations to sustainability, social aspects must be included in storylines (Malin & Ryder, 2018).

A simple opportunity exists for this challenge, already built into the SSP framework. A new set of driving forces which are more representative of sustainability needs should be developed. Many of the studies which extended the SSPs already understood the need for modification of the base SSP driving forces (e.g., Absar & Preston, 2015; Jenkins, Malho, & Hyytiäinen, 2022). The driving forces which are explored in any given study may depend on the research question or case study, but developing sustainability-focused driving forces should be a priority. Szetey et al., (2021) modified the SSP driving forces by adding new ones relevant to the case study and removing those which were not. Another possibility would be to align the driving forces with the sustainable development target space as described by van Vuuren et al., (2022), which would require both a new scenario space (perhaps described by the *target clusters*) and new list of drivers linked to the *normative goals.*

3. Model coupling constrains storylines

The third challenge for the use of SSPs for sustainability concerns modelling applications. In recent years, there has been heightened interest in the modelling community about modelling social aspects, and there is growing understanding that the omission of these social factors from scenarios and the modelling on which it is based risks the biasing of conclusions in favour of actions which are technological or easier to quantify (Trutnevyte et al., 2019). Gambhir et al., (2022) discuss how the established Integrated Assessment Modelling (IAM)-dominated modelling paradigm (of which the SSPs are part) is inadequate simply due to the narrow focus of what IAMs are able to model. Stoddard et al., (2021) go even further, laying some of the blame of unsatisfactory progress on reducing climate emissions upon this narrow focus of IAMs and likewise constrained social imaginaries. If such concerns are being raised *within* the disciplines for which the SSPs were designed, it is of even greater import in a diverse and expansive field such as sustainability science.

The opportunity here is to decouple IAM modelling requirements from scenarios. IAMs are one modelling paradigm, but socioecological modelling has been grappling with the representation of social and biophysical elements for many years and could provide guidance for alternative ways to model futures, whether it is agent-based (Filatova, Verburg, Parker, & Stannard, 2013), systems (Elsawah et al., 2020; Martínez-Fernández, Banos-González, & Esteve-Selma, 2021), or other types of modelling. Additionally, it may be worth examining whether every element of scenario storylines needs to be quantitatively modelled. Sensitivity analysis on models will identify variables of greater and lesser impact on outcomes, and it could be argued that those of lesser impact are essentially 'omitted' from the modelling decision space, so not all variables are required (Campolongo, Cariboni, & Saltelli, 2007). Expanding imaginaries of what could be possible in a sustainable future may be a more desirable outcome than quantifying every aspect of those possibilities (Eschrich & Miller, 2021; Stoddard et al., 2021; Strand, Saltelli, Giampietro, Rommetveit, & Funtowicz, 2018). Co-production can be one method for broadening the focus of scenarios (Melbourne-Thomas et al., 2022; Wyborn et al., 2020). Qualitative modelling such as envisioning (Bryan et al., 2013) or conceptual modelling methods (Easdale & López, 2016; Sedlacko, Martinuzzi, Røpke, Videira, & Antunes, 2014) can incorporate imaginaries and co-production, and Moallemi et al., (2021) examined the range of qualitative and quantitative methods for developing pathways to sustainable futures.

4. Economic outcomes

The fourth challenge is aligned with the issue of limited social imaginaries and restrictions imposed by IAMs, but this time in respect of existing economic systems. Economic outcomes in the SSP scenarios are only represented by positive GDP growth, unequal growth, or negative growth associated with negative social and environmental outcomes. Given the increasing discussion over whether sustainability transformation is even possible under existing neo-classical economic paradigms considering the contribution of economic growth to biodiversity loss (Otero et al., 2020) and to inequality (Stiglitz, 2016), the absence of a degrowth scenario in the SSP reference scenarios is an additional concern for their use in a sustainability context. This is an issue which has been raised by other authors (Keyßer & Lenzen, 2021; McGreevy et al., 2022; e.g., Wiedmann et al., 2020) but is of particular concern when research is intended to examine imaginative and transformative futures (Pereira, Sitas, Ravera, Jiménez-Aceituno, & Merrie, 2019).

There have been calls in the broader futures literature to address this focus on economic growth, with some concrete examples of how to achieve degrowth in practice (Hickel et al., 2022). Feasible alternative social and economic policies for an equitable and low-carbon future have been explored and modelled (Bodirsky et al., 2022; D'Alessandro, Cieplinski, Distefano, & Dittmer, 2020). Ecological macroeconomics models that include degrowth futures exist, including challenges such as large-scale inequality, global security, and financial wellbeing (Hardt & O'Neill, 2017). Sustainability SSPs should be less conservative and include aspects of this emerging line of inquiry that challenges the growth-driven paradigm, as models cannot continue to rely on speculative negative-emissions technologies. The research on alternatives to economic growth already exists, and could be incorporated into the SSP framework, supporting both climate and sustainability science.

5. Types of scenarios

The fifth challenge is with respect to how the SSPs are constructed. Earlier the distinction between exploratory and goal-oriented scenarios was made; the SSP scenarios are exploratory pathways – driving forces exploring how futures may develop based on socioeconomic assumptions (Skea, van Diemen, Portugal-Pereira, & Khourdajie, 2021). They can be criticised for their specific exploratory approach in two ways. First, the SSPs narrow the future's uncertainty space to five distinct scenarios while missing the effects of deep uncertainties and many other possible states of the world that fall between or outside the five-scenario set (Lamontagne et al., 2018). Second, exploratory scenarios like the SSPs are useful for answering questions of 'what could happen' and understanding 'what-if' questions such as how a series of future events could impact the achievement of sustainability goals. But they are insufficient for understanding what solutions and measures should be put in place to meet desired sustainable futures, for example, how to meet the SDG targets by 2030, rather than concluding that the targets cannot be met under the scenarios analysed.

Exploratory scenarios are better at exploring 'what-if' outcomes, however goal-oriented scenarios can be used alongside exploratory scenarios to examine a range of futures including those examining how to reach specific goals. More research is needed on developing normative scenarios for sustainability that can guide the achievement of the desired future either within the limits of existing system structures (preserving scenarios) or through systemic change (transformative scenarios; Maier et al., 2016). One important opportunity to specifically address the concern about deep uncertainty is to use exploratory thinking and modelling more widely in sustainability scenarios (Bankes, 1993; Moallemi, Kwakkel, de Haan, & Bryan, 2020). Its core idea is to abandon the notion of best-guess futures in an environment fraught with shocks and surprises, not amenable to probabilistic characterisation, and to let go the ideal of projecting the most-likely development of futures. Instead, the exploratory approach draws on local-scale dynamics (e.g., natural variability, conflicting policy objectives, stakeholders' divergent preferences) to systematically explore the implications of many plausible and equally valid values and options about the future in pursuit of a shared understanding, increasing the robustness of final outcomes. There are several examples of exploratory approaches in various applications (Dolan et al., 2021; Hadjimichael et al., 2020) that can inform the future of sustainability SSP work.

6. Diversity in scenarios

As sustainability science is often represented as a transdisciplinary endeavour (Wyborn et al., 2019), imposing these five top-down SSP scenarios on research can be viewed as problematic from a diversity perspective. Understanding whose voices are heard in the development of scenarios is a vital component of knowledge co-production, and the reality is that despite significant efforts, the SSPs are often viewed as being a product of a research collaboration that was gender- and career stage-biased with teams dominated by researchers from affluent Global North countries. The SSPs, as an extension of climate science, can be interpreted through Jasanoff's (2010) criticism that climate science "detaches global fact from local value, projecting a new, totalizing image of the world as it is, without regard for the layered investments that societies have made in worlds as they wish them to be." The SSPs attempt to be impersonal and apolitical, and their universal focus leads to a disconnection from subjective and local values. Sustainability science is a very context-dependent field and, unlike global issues, sustainability concerns can be very local and heterogenous. A core sustainability principle is equity (of gender, race, ethnicity, Indigeneity, ability, and socioeconomic status) and those with lived experience of inequality should be involved in imagining their own futures.

Diversity in scenario development, and in what is represented in the storylines, are two issues which are obviously connected. Transdisciplinary collaboration for scenario development in sustainability science is certainly not a new idea. But its application is often limited to local scales, and perhaps its co-production has not been as inclusive as it could have been. Opportunities for addressing this include collaborating with social and political scientists (widening the positionality of the research team; Steger et al., 2021), co-producing new scenarios with a diverse range of participants (Andreotti, Speelman, Van den Meersche, & Allinne, 2020; Falardeau, Raudsepp-Hearne, & Bennett, 2019; McEwen et al., 2022), and more heterogenous scenarios which are tailored to specific locations (Moallemi et al., 2021; Szetey et al., 2021). Incorporating diversity and pluralism into scenarios via knowledge co-production is important for enabling sustainability transformation (Chambers et al., 2022).

Conclusion

The SSPs have been used within the climate change and integrated assessment communities for nearly a decade and they have been widely adopted across a range of disciplines which employ scenarios. However, there have been few attempts to contextualise the SSPs beyond their original conception for climate change, and many applications (including in sustainability science) have used them with no change from their original context. We believe that the SSP framework can be adapted to overcome these limitations by understanding that the scenario space is not fit-for-purpose for sustainability, and that the driving forces which build the scenario narratives are likewise not sufficiently comprehensive. Additionally, transdisciplinary approaches should be used in creating and developing any new scenarios and boundaries. We have identified opportunities, but we believe that ultimately having a consistent set of scenarios for sustainability is only necessary at the global scale. One of the characteristics of sustainability as a discipline is its heterogeneity – context matters when exploring sustainable futures, and that context is at risk of being suppressed or erased if heterogeneity is not recognised. Several of these challenges are interlinked and much could be addressed with some simple rethinking of the scenario space and driving forces. Regardless, sustainability scholars should be cautious of using the climate-SSPs unquestioningly in their research applications at any scale, and as a community we should prioritise development of a fit-for-purpose scenario space and set of driving forces for sustainability SSPs. While we believe that the dogmatic use of the five reference SSPs for sustainability transformation research significantly limits the potential futures that are being examined, and risks biases towards technological and economic growth outcomes over social, ecological, and equity outcomes, we understand that researchers had good intentions for choosing to use the SSPs in their original form. Science progresses by building upon earlier advances, and for this period of time, the climate SSPs were the evolution of scenarios that were used in sustainability science. It is time to synthesise our collective learnings from using the SSPs and move on to a more fit-for-purpose option for our field, much as IPBES have done. Sustainability science does not have an intergovernmental body to oversee its direction as the IPCC and IPBES does for its fields, so the community will need to self-organise to some extent in order to address these challenges. We recognise that development of new scenarios takes time and we are currently only seven years away from the horizon of the SDGs, so we should look beyond 2030 for the scope of these sustainability-SSPs.

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Author contributions

KS conceived the idea for the article. KS, EM, BB, and SC contributed knowledge, wrote, and edited the article.

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Conflicts of interest

No conflicts of interest have been declared by the authors.

Data availability statement

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