



Improving regional applicability of the UK shared socioeconomic Pathways through iterative participatory co-design

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ABSTRACT

Regional analyses of risks from climate change require reproducible, consistent and robust approaches to downscaling global socioeconomic scenarios, with coherent processes that work across multiple projects and communities. We address this need by developing an iterative approach to stakeholder-based Shared Socioeconomic Pathway (SSP) downscaling and co-design, enabling us to extend SSPs while maintaining their consistency from global to sub-national scales. We apply this approach to extend a set of SSPs for the United Kingdom, developing a broad range of user-oriented scenario products including (a) a set of key categories of socioeconomic drivers and their dimensions, (b) extended scenario narratives, (c) system diagrams, and (d) semi-quantitative trends of key socioeconomic indicators. Importantly, the co-design process outlined in this study was implemented fully online, providing valuable lessons on the implications of the online approach for participatory involvement, stakeholder inclusiveness and representativeness. In addition to presenting the approach and its resulting scenario products, we highlight how it contributes to adding detail and nuance, as well as geographic, temporal and sectoral extension to the scenarios. Furthermore, we discuss the benefits of the approach as a reproducible and robust roadmap to SSP downscaling, with respect to deepening the co-design process and increasing scenario legitimacy and validation.

1. Introduction

Socioeconomic conditions directly influence societal and environmental exposure, vulnerability and adaptability to climate

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change. In the future, socioeconomic conditions may vastly differ from today, and their changes are likely to interact with climate change impacts in complex and non-additive ways (Harrison et al., 2015). Thus, it is crucial that alternative scenarios of future socioeconomic changes are developed and combined with climate change scenarios to fully assess climate risk and explore adaptation solutions that enhance climate resilience (Dunford et al., 2015). The most widely used socioeconomic scenarios in climate research are the Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2020) (Box 1). However, the coarse resolution of global-scale SSPs has proven insufficient for more fine-grained needs of policy- and decision-makers at national and sub-national scales (Frame et al., 2018). Consequently, multiple efforts to downscale SSPs to regional contexts have been pursued worldwide.

Quantitative, data-driven approaches have been used to downscale the global SSPs. Such approaches utilise the narratives or quantified indicators from the global SSPs as boundary conditions and extend them with contextual regional and sectoral knowledge from the literature and local databases. Examples include Absar and Preston (2015) for the Southeastern US, Reimann et al. (2018) for the Mediterranean coastal zone, and Rohat et al. (2018) for assessing human vulnerability in Europe. Alternative approaches start with local stakeholder perspectives to develop these lower-scale scenarios that are then linked with the global SSPs. Such approaches are often co-developed through the involvement of national and sub-national stakeholders. Examples include the New Zealand SSPs, where stakeholders provided feedback on the downscaled scenarios (Frame et al., 2018); the Japan SSPs (Chen et al., 2020) and Baltic Sea SSPs (Zandersen et al., 2019), where stakeholders were involved in identifying key drivers and matching them with the global SSPs; and the Finland SSPs for the agriculture and food sectors, which were co-developed with stakeholders using larger-scale European SSPs as starting information (Lehtonen et al., 2021).

Stakeholder engagement has been widely acknowledged as a powerful feature of scenario co-design (IPBES, 2016; Rounsevell and Metzger, 2010), enabling professional and personal knowledge (e.g. sectoral, geographical, knowledge of different local contexts) to be captured within regional SSPs. Positioning a diverse range of stakeholders as central to the scenario downscaling process also increases the credibility, legitimacy and saliency of the regional scenarios (Rounsevell and Metzger, 2010) and increases the utility of the final downscaled scenario outputs (Reed et al., 2013).

The growing number of regional SSPs has led to calls for reproducible and consistent methods for the use of the SSPs across scales that meet needs across multiple projects and communities (O'Neill et al., 2020). This has been rarely the case, as most participatory scenario downscaling endeavours to date have represented a one-off process, with a single iteration of stakeholder engagement (e.g. a single workshop) or engaged a limited group of stakeholders within a short time frame (see examples above). This is further supported by recent literature that has called for regional scenarios that meet the needs of a wider community of SSP users (including researchers, practitioners and policy-makers) by extending their geographic, sectoral and temporal detail (UK Climate Resilience Programme, 2019), while maintaining consistency across the growing richness of multi-scale SSP scenarios in terms of socioeconomic assumptions and trajectories (O'Neill et al. 2020; Cradock-Henry et al., 2021; Elsayah et al., 2020).

In this article, we present an iterative approach to participatory scenario co-design, which can be used as a reproducible and robust 'blueprint' for improving the regional applicability of the SSPs. We apply this approach to extend an existing version of UK-specific SSPs (UK-SSPs) to meet the needs of a wider range of users across multiple projects and communities (both researchers and policy-makers) (see Supplementary Material A Box S 1 for details). Thus, we develop an array of extended exploratory scenarios for the UK, following the SSP scenario matrix (O'Neill et al. 2014, Box 1). We show how advances in scenario products can be gained due to the iterative co-design approach, particularly delivering richer geographical, sectoral and temporal detail in SSPs while maintaining their internal cross-sectoral and cross-scale consistency. Furthermore, we demonstrate how the second iteration in the participatory approach allowed the regional SSP logic and assumptions to be thoroughly validated leading to updated and enriched scenario elements.²

2. Methods

The iterative approach spans across two multi-year projects (Supplementary Material A, Box S 1). It builds on an original version of the UK-SSPs ("Version 1 UK-SSPs", (Pedde et al., 2021)) to produce an extended and validated version through a second iteration of scenario co-design ("Version 2 UK-SSPs"). The co-design process extended the UK-SSPs geographically, temporally and sectorally based on intensive stakeholder participation, including an online stakeholder workshop, a set of semi-structured interviews and a follow-up survey (Fig. 1). The process focused on integrating national stakeholder knowledge on locally-relevant drivers (i.e. socioeconomic driving forces of future climate change, including climate adaptation and mitigation) with high-level information from the European and global SSPs to validate and update, where needed, the Version 1 UK-SSPs. The fully online design of the "second iteration" of the process, adopted in reaction to the recent Covid-19 pandemic, allowed us to test the reproducibility of some of the SSP downscaling methods between physical and online workshop processes (Davies et al., 2021; Tobin et al., 2020).

The approach delivered a range of coherent qualitative and semi-quantitative outputs for use by climate research and policy communities and further modelling (Merkle et al., in review), including extended narratives, system diagrams visualizing UK-SSP internal logic (i.e. the relationships between key driving forces), and key socioeconomic indicators with their semi-quantitative trends (Fig. 1).

The methodological approach of this study was guided by the project's User Panel (see Supplementary Material A Box S 1 for

² In this paper, we define scenario elements as the occurrences of specific themes and their development over time, e.g. the element of a "green race" or the element of introducing the universal income. In cases where these refer to specific sections of the scenario narratives, we denote them as narrative elements.

Box 1**Shared Socioeconomic Pathways (SSPs).**

Shared Socioeconomic Pathways (SSPs) are a set of socioeconomic scenarios designed at the global scale through research processes related to the Intergovernmental Panel for Climate Change (IPCC). SSPs have been developed to help integrate societal futures into studies of climate impacts, adaptation and mitigation, aiming to support international climate-related agreements, decision-making and research (O'Neill et al., 2020, 2017, 2014). The five SSPs represent alternative development trajectories of socioeconomic drivers such as population, economic growth and technological development that underpin challenges to climate change adaptation and mitigation. The qualitative SSP narratives have served as the basis for a large number of quantification and modelling efforts, primarily at the global scale, related to climate change drivers, risks and response options (O'Neill et al., 2020), e.g. land use change (Popp et al., 2017), greenhouse gas emissions (Meinshausen et al., 2019), air pollution (Rao et al., 2017), exposure to climate hazards (Byers et al., 2018; Rohat et al., 2019), and analyses of climate implications for poverty (Hallegatte and Rozenberg, 2017).

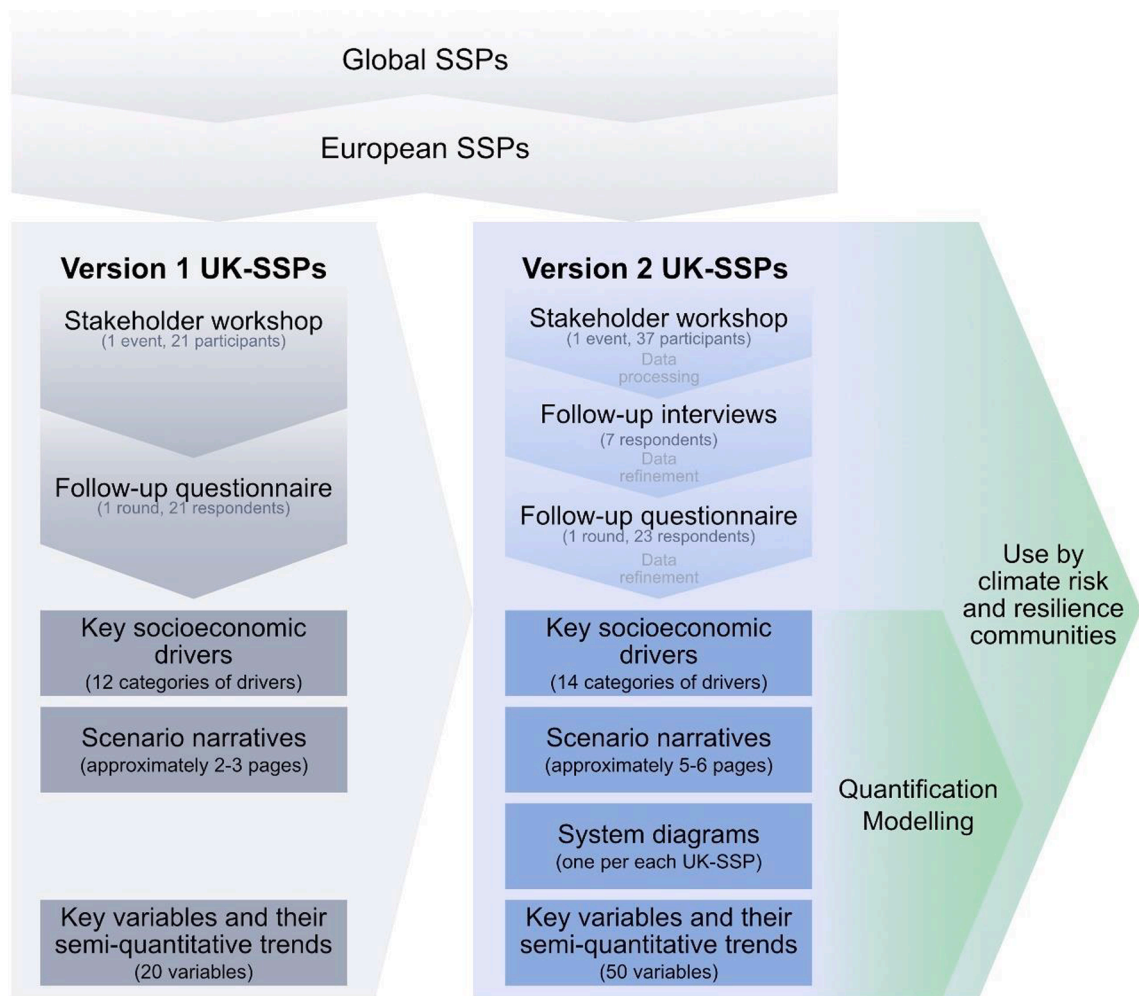


Fig. 1. The iterative process of SSP downscaling for the UK (see Supplementary Material A Box S 1 for details of the iterations). The scope of this paper is highlighted in blue (more details are given on the individual steps and outcomes in the Methods and Results sections). The green fields symbolize an envisioned use of the scenario products, e.g. for quantification of the selected socioeconomic indicators as described in Merkle et al. (in review).

details).

2.1. Starting point: Version 1 of the UK-SSPs

We built on an existing set of UK-SSPs that were downscaled from the global and European SSPs to the UK (Pedde et al., 2021). Version 1 UK-SSPs were developed through a participatory process involving a single physical workshop with 21 stakeholders and two follow-up questionnaire surveys (Fig. 1). Version 1 UK-SSP focused on socioeconomic trends relevant for climate adaptation and mitigation, and were developed for three time periods (present to 2040; 2040 to 2070; 2070 to 2100) for the UK national level, without sub-national detail. Version 1 scenario outputs consisted of 2–3 page narratives and a table of semi-quantitative trends for 20 socioeconomic indicators. Unlike their updated Version 2, Version 1 UK-SSPs did not include system diagrams for individual scenarios.

2.2. Participatory co-design process for Version 2 of the UK-SSPs

2.2.1. Online stakeholder workshop

The second iteration of the scenario co-design process, focal to this study, included a wide range of stakeholders and was centred around an online participatory workshop (see [Supplementary Material A Box S 2, 3 and 4](#) for full detail). The online workshop (held in May 2020) involved 37 stakeholders, covering a wide diversity of organisations, sectors, and individual and geographic characteristics, and was carried out over 4 days, with professionally facilitated, highly interactive sessions. Involving a broader set of stakeholders in the second iteration of the scenario co-design process provided the potential to democratise the process and increase the legitimacy and usefulness of national-scale SSPs (see [Supplementary Material A Box S 2](#) for a detailed description of the stakeholder selection). The participation of all stakeholders in the workshop was voluntary, without reimbursement. All participants' input was either directly anonymous, or anonymized before further processing.

Throughout the sessions, the stakeholders participated in an array of exercises, gradually building on each other to (1) elicit key categories of socioeconomic drivers and their dimensions, (2) further develop, refine and extend UK-SSP scenario narratives, (3) develop system diagrams representing the internal logic of each scenario, and (4) develop a broadened set of key socioeconomic indicators with their semi-quantitative trends for each scenario (see [Supplementary Material A Box S 2, 3 and 4](#) for a detailed description of the workshop design, workshop agenda, tasks and example templates). In summary, the first two sessions of the workshop focused on participatory identification and clustering of UK socioeconomic drivers considered to be particularly important and uncertain for determining the socioeconomic development of the UK over this century, and their mapping to the UK-SSPs. These drivers were used to provide context in the next steps of developing the UK-SSPs narratives. The two sessions were based on Mentiimeter voting (<https://mentiimeter.com/>), follow-up discussion and live adjustments to a screen-shared summary spreadsheet database. The enriching and expanding of the UK-SSP scenario narratives was carried out over three sessions, detailing the descriptions of the scenario development in three time periods (present to 2040; 2040 to 2070; 2070 to 2100). These sessions were based on moderated discussion and editing of a shared text document. Another session focused on participatory co-design of system diagrams to reflect on and visualise the relationships between key driver categories within each UK-SSP. The session used the Visual Understanding Environment (VUE) software (<https://vue.tufts.edu/>) to build and live-edit a system diagram during a discussion with the participants, using screen sharing. The final two sessions focused on participatory development of semi-quantitative trends for specific indicators for the UK-SSPs and deliberating a consensus version of the trends. The session used screen-shared slides with background information and pre-prepared blank charts for live development of the trends, based on the stakeholder discussion.

2.2.2. Data processing

The information created by the online workshop was processed (see [Supplementary Material A Box S 5](#) for details) to check the coverage of key socioeconomic driver categories throughout the scenario narratives, and the consistency across the five SSPs in terms of both content and presentation for the narratives and systems diagrams. These analyses allowed us to bring together the different local/regional knowledge, viewpoints and insights from stakeholders from each of the four UK nations, whilst maintaining consistency between the content of the UK-SSP narratives and the European/global SSPs.

Consistency with the European and global SSPs was reached by several means. First, within the stakeholder workshop, the broad narratives of the global and European SSPs (Kok et al., 2019) were presented to the stakeholders who were then asked to map the categories of UK socioeconomic drivers and their dimensions onto the SSP scenario framework. Second, the Version 1 UK-SSP narratives (already based on European and global SSPs) were presented to participants as Google documents, with stakeholders given sufficient time to read and understand the detail of the storylines and their scenario logic. Third, the participants were provided with benchmark trends in Gross Domestic Product (GDP) and population growth in the UK according to different global SSPs as an entry information point to the workshop activities on semi-quantitative trends (these quantified projections were obtained from the International Institute for Applied Systems Analysis (IIASA) Public SSP Database; (<https://tntcat.iiasa.ac.at/SspDb>)). Finally, during the data processing, the consistency with the European and global SSPs was maintained on both a qualitative level (through cross-checking the Version 2 UK narratives with the global and European SSP narratives) and semi-quantitative level (by cross-checking the resulting semi-quantitative trends with trends in indicators quantified for SSPs in the IIASA database where available). The data processing stage resulted in a set of draft full narratives, comprising an abstract, detailed description of the scenario development in three time periods, followed by summary paragraphs for each of the four UK nations that build on the full narrative, emphasising differences of each nation from the full narrative or providing specific regional examples. In addition, we refined the stakeholder-based inputs related to the system diagrams for the five UK-SSPs, and the socioeconomic indicators and their semi-quantitative trends (see [Supplementary](#)

Material A Box S 5 for details).

The consistency of scenario logic within each Version 2 UK-SSP was ensured by (1) developing the system diagrams, which highlighted the relationships between the development in different driver categories, and (2) cross-checking the system diagrams with the scenario narratives both during the stakeholder workshop and at the stage of data processing. To this end, the workshop session on developing the system diagrams was placed between two sessions developing the scenario narratives, so that any inconsistencies or missing relationships revealed could be corrected or integrated consistently in the scenario narratives (see [Supplementary Material A Box S 2, 3 and 4](#) for a detailed description of the workshop design, workshop agenda, tasks and example templates). In addition, the co-developed key socioeconomic indicators were cross-checked with the updated narratives and adjusted to ensure consistency (see [Supplementary Material A Box S 5](#) for details).

The consistency of differences across the Version 2 UK-SSPs was ensured by the development of the semi-quantitative trends and their comparison between UK-SSPs.

2.2.3. Follow-up online interaction with stakeholders and the refinement of the UK-SSPs

During the data processing, we identified gaps in thematic, sectoral, temporal and geographic coverage, as well as inconsistencies between scenario elements. These were further addressed and filled-in through an array of targeted semi-structured interviews and a follow-up survey.

2.2.3.1. Semi-structured interviews. The main gap identified in the draft narratives was on nation-specific detail. Hence, seven semi-structured interviews were organised during August and September 2020 with selected workshop participants from England, Wales, Scotland and Northern Ireland. The interviews lasted approximately 60 min, and each UK-SSP was covered within 10–15 min. They were conducted by one interviewer and two note-takers from the research team. The interviews covered a range of questions for each nation including how might devolved governance develop, how might changes in social structure and public attitudes emerge,

Table 1

The 14 driver categories and their opposite dimensions.

	Version 1 UK-SSPs			Version 2 UK-SSPs			Type of update
	Driver category	Opposite dimensions		Driver category	Opposite dimensions		
1	International relations	Nationalist	Global integration	International relations	Protectionist	Globalised	Unchanged
2	Social structure	Egalitarian (many)	Privileged (few)	Social structure	Egalitarian, many	Privileged, few	Unchanged
3	Evolution of societal attitudes & norms	Disillusioned, disengaged & disempowered	Engaged, empowered & inspired	Public attitudes	Disillusioned, disengaged & disempowered	Engaged, empowered & inspired	Unchanged
4	Travel and mobility	Low	High	Transport & mobility	Low mobility	High mobility	Unchanged
5	Government structure	Socially cohesive and effective	Socially divisive and ineffective	UK/Devolved Administration policy & governance	Devolved	Centralised	Dimension change
6	Technology & data	Net benefit to social-ecological-economic system	Net damage to social-ecological-economic system	Technology	Slow development	Rapid development	Dimension change
7	Nature of the economy	Non-monetary driven system	Traditional money-based economy	Economic development	Traditional market-based systems	Novel economic systems	Dimension change
8	Demographics	Low proportion of working population	High proportion of working population	Demography	Lower proportion of people aged over 65	Higher proportion of people aged over 65	Dimension change
9	Land-use & environmental policy	Strategic and planned for benefits of the people	Free-for-all unregulated	Natural resources	Resource-friendly, sustainable use	Resource over-exploitative, unsustainable use	Driver redefinition
10	Food security & consumption	Resource-friendly practices	Resource-exploitative practices	Food	Low meat diet	High meat diet	Driver redefinition
11	Green energy	Gradual transition	Disruption	Energy	Low carbon	High carbon	Driver redefinition
12	Public & environmental health	High-impact pest and diseases with high ability to control and respond	Low-impact pest and diseases with high ability to control or respond	Health	Low investment	High investment	Driver redefinition
13	NA	NA	NA	Education	Low investment	High investment	Newly introduced driver
14	NA	NA	NA	Response to global shocks	Persistence	Transformative change	Newly introduced driver

which economic activities, energy sources, natural resources and land uses might be prioritised, and how might relationships between the nations develop (see [Supplementary Material A Box S 6](#) for interview guides). We processed the responses (see [Supplementary Material A Box S 5](#) for further detail) and used these to further extend the draft narratives, particularly the national paragraphs, leading to full narratives of approximately 5 to 6 pages.

2.2.3.2. Follow-up survey. These near-final narratives were sent to the 37 stakeholders who participated in the workshop and a questionnaire used to gather feedback on whether we had correctly interpreted and elaborated their contributions (see [Supplementary Material A Box S 8](#) for the questionnaire outline). The questionnaire asked the participants whether the narrative reflected the discussions during the workshop (on a scale between 1 for not at all and 5 for fully). Several multiple-choice questions were included to get further information on selected elements of the narratives which required further feedback. Finally, we asked whether the references to particular places or regions in the narratives represent reasonable illustrations, to verify whether these were correctly captured in the process. The respondents also had the option to access all the draft narratives and make comments directly in the text.

Questionnaire responses were received from 23 respondents (68 % response rate). The majority of respondents thought that the narratives were accurate representations of the workshop discussions (mean score 4.3 out of maximum 5, ranging between 3.7 and 4.8 for the individual scenarios). The responses to the multiple-choice questions helped shape final details of the narratives. The vast majority of respondents considered the references to geographic locations in the narratives accurate, and did not make additional edits or comments in the narratives.

We used the feedback from the stakeholder questionnaire to make final refinements and finalise the scenario products (see [Supplementary Material A Box S 9](#) for the questionnaire responses).

See [Supplementary Material A Box S 4](#) for the illustration of raw results of all stakeholder engagement activities. The final results are provided in the Results section below and [Supplementary Materials B, C and D](#).

3. Results

Four complementary products were created for each UK-SSP: (1) updated and extended UK-specific driver categories and their dimensions; (2) updated and extended qualitative UK-SSP narratives, (3) system diagrams visualizing the internal logic of the narratives and connections between their key socioeconomic driver categories, and (4) semi-quantitative trends of 50 socioeconomic indicators capturing the dynamics within each UK-SSP. This array of outputs was designed to provide a variety of perspectives on the internal logic and consistency of the scenarios and allow for multiple types of further processing.

3.1. Driver categories and their dimensions

The second iteration of the scenario development process enabled validation of the set of driver categories identified in the Version 1 UK-SSPs ([Pedde et al., 2021](#)) that were considered particularly important for future UK socioeconomic development this century. [Table 1](#) compares Version 1 with Version 2 driver categories and details their respective pairs of key opposite dimensions, as identified by the stakeholders.

While some of the driver categories remained unchanged, in other cases, either the definition of the driver category or its dimensions were updated. The reasons for the updates to the drivers and their categories by the participants compared to Version 1 was related to: (1) the new and broader group of involved stakeholders, (2) the broader thematic focus, and (3) the timing of the exercise (post the Covid-19 pandemic break-out).

The largely unchanged driver categories included International relations, Social structure, Public attitudes, and Transport & mobility. The definitions of the driver categories UK/Devolved Administration policy & governance, Technology, Economic development, and Demography were also largely unchanged but their key dimensions were updated. For UK/Devolved Administration policy & governance, the stakeholders found the level of centralization/devolution more important than the Version 1 dimensions of social cohesion and effectiveness, which were incorporated into the updated driver categories of Public attitudes and Social structure. In the case of Technology, the updated dimensions focused on the pace of technological development instead of the quality of technology impacts on the surrounding social-ecological system (either positive or negative). For Economic development, the Version 1 dimensions were considered too specific (e.g. the dimension of “Non-monetary” driven system) and changed to more general dimensions of a “traditional market-based system” and “novel economic system”. A slight shift in the dimension angle was apparent in the case of Demography, where the new dimensions focused on the proportion of elderly people, rather than the Version 1 “proportion of working population”.

The driver categories of Natural resources, Food, Energy, and Health were completely redefined and generally simplified, shifting towards the sustainability of their use, meat consumption, carbon footprint and the level of public investment, respectively. In addition, two new driver categories were introduced, namely Education and Response to global shocks; the latter related to stakeholder’s experiences during the Covid pandemic.

3.2. UK-SSP scenario narratives

The final UK-SSP narratives described socio-economic developments for the UK as well as each of the four UK nations (England, Scotland, Wales and Northern Ireland). Each narrative contained information on general trends in the final 14 key driver categories

(Table 1).

In summary, UK-SSP1 envisions the UK as a sustainable, egalitarian and co-operative society transitioning to a fully functional circular economy, which leads to healthier lifestyles, improved well-being, sustainable use of natural resources, and more stable and fair international relations. It represents a scenario with a low carbon economy and high capacity to adapt to climate change. UK-SSP2 is a world in which strong public–private partnerships enable moderate economic growth but inequalities persist. It represents a highly regulated society that continues to rely on fossil fuels, but with gradual increases in renewable energy resulting in intermediate adaptation and mitigation challenges. UK-SSP3 shows how increasing social and economic barriers may trigger international tensions, nationalisation in key economic sectors, job losses, and eventually a highly fragmented society with the UK breaking apart. It represents a society where rivalry between regions and barriers to trade entrench reliance on fossil fuels and limit capacity to adapt to climate change. UK-SSP4 represents a highly unequal scenario with large differences in income across segments of UK society. Business and political elites dominate and curtailment of welfare policies leads to the majority of the population feeling excluded and disengaged from decision-making. The business and political elite facilitate low carbon economies but large differences in income across segments of UK society limits the adaptive capacity of the masses. UK-SSP5 shows the UK transitioning to a highly individualistic society where the majority become wealthier through the exploitation of natural resources combined with high economic growth. It represents a technologically advanced world with a strong economy that is heavily dependent on fossil fuels, but with a high capacity to adapt to the impacts of climate change.

For the complete Version 2 narratives, see [Supplementary Material B](#).

3.2.1. Elements of the scenario narratives challenged and changed during the process, compared to the Version 1 UK-SSPs

Several differences between UK-SSP Version 1 and Version 2 narratives emerged from the second iteration in the scenario development process. These principally involved strengthening, discarding, emphasising, elaborating or softening scenario elements overall or in terms of their spatial or temporal detail. In the following sections we present stakeholders' motivations for these changes with illustrative examples.

3.2.1.1. Addressing consistency issues: Strengthening scenario logic and reframing scenario elements. The most substantial changes compared to the Version 1 UK-SSPs were related to addressing consistency issues within the scenario narratives. This type of change included larger updates in the scenario narratives, adjusting their logic and framing in order to strengthen their internal consistency. It mostly targeted the initial parts of the narratives and strengthened the logic of how the scenarios move from the present to the future. For instance, in UK-SSP1, the logic of how a series of global shocks would facilitate a major shift towards pro-sustainability public attitudes was strengthened; in UK-SSP2, consistency issues related to how the collapse of the healthcare and pensions systems in the UK would lead to the formation of public–private partnerships were addressed; in UK-SSP3, the interplay between the breakdown of the international order and the internal UK drivers was considerably elaborated; whilst in UK-SSP4, the dynamics between business and political interests in the establishment of the National Plan were clarified, particularly in the transformation of green energy systems and how this would lead to exacerbating regional inequalities. UK-SSP5 experienced the least changes from the Version 1 narrative, with the logic being strengthened around how international and financial shocks lead to decreasing public support for green taxes and changes in domestic public policy and investments in favour of fossil fuels.

Other examples of profound changes related to scenario consistency included in UK-SSP1 where participants found the Version 1 element of a technological “green race” among the UK nations inconsistent with the overall collaborative framing of the scenario. Thus, the element was reframed and the emphasis shifted from a “green race” to a “green alliance”, focusing on collaboration instead of competition. In UK-SSP4, participants challenged the extensive plantations of leisure drugs, which were partly substituted with other economic activities, such as low-paid service and retail jobs, in poorer post-industrial regions of the UK.

3.2.1.2. Extending regional detail. Increasing the regional detail of the UK-SSPs for England, Wales, Scotland and Northern Ireland was one of the major aims of the process. Thus, each narrative was expanded by four nation-specific sections, detailing potential future development in each UK nation (see [Supplementary Material B](#) for the full version of the nation-specific narratives).

The regional aspects of several driver categories were substantially expanded in the process. First, UK/devolved governance was detailed, elaborating particularly on the role of the government in each of the four UK nations, the powers that were devolved or centralised in each scenario, and the intensity of regional disparities within each UK nation, such as the North-South divide in England. Second, additional regional detail was included on the differences between public attitudes and social structure in the four UK nations, including the level of inequality across and within the UK nations, and different types of values and motivations in different social groups across the UK nations. Regional detail was added on the movement of the population, industries, services and resources across and within the four nations, particularly between geographic regions and between rural/urban areas. Finally, regional differences in the energy mix were included.

The dynamics across the four UK nations differed the most in UK-SSP3, as this scenario included the strongest tendency to regionalisation and represented the only narrative in which the UK breaks apart into four independent nations and then into smaller micro-states. Thus, UK-SSP3 was the richest in content in terms of the regional and spatial aspects of the narrative. Changes in regional dynamics related to the North-South divide within England are also emphasised across the scenarios, showing decreases in UK-SSP1 and UK-SSP5 as the UK becomes more equal, whilst increasing in UK-SSP4 where the role of southeast England and particularly London dominates as a powerful political and business hub.

3.2.1.3. Adding thematic detail. Adding thematic detail stemmed from participants' perception that certain narrative elements were: (1) too general and more detail was needed to increase their specificity, (2) too soft and needed to be strengthened and made more extreme, (3) entirely missing and needed to be newly introduced to the narratives (e.g. to fill gaps in coverage of the driver categories), and (4) confusing, unclear or not nuanced enough, and needed to be refined or rephrased. Participant's motivations to add thematic detail often spanned more than one of these categories.

For instance, in UK-SSP1, the description of an egalitarian society became much more pronounced, emphasising that the sustainability agenda spans across the entire society, not just a privileged few. Further nuance was also added on the use of GMOs in UK-SSP1, emphasising how ownership issues and unwanted side-effects and risks are resolved. In UK-SSP2, the participants introduced the theme of universal basic income as an element to strengthen the inequality dynamics in the scenario. In addition, the element of urban vertical agriculture was further specified in UK-SSP2, and consistently linked with the high level of urban planning to resolve land use conflicts in rural areas and free up more space for nature conservation. In UK-SSP3, the general picture of the collapse of higher-level governance structures was enriched by adding more detail on newly emerging semi-independent micro-states, filling in the governance void. In UK-SSP5, the element of "rewilding" was further strengthened and adapted to local contexts, particularly in Wales (rural economy focusing on "niche products") and in Scotland ("tourism, leisure and game meat"). The "rewilding" framing also clarified better the UK-SSP5 logic of "uplands" and "lowlands" economic activities.

3.2.1.4. Removing thematic detail. Contrary to the above, certain scenario elements were perceived as (1) too specific, or (2) too extreme or exaggerated. In such cases, excessive thematic detail was removed or softened down to slightly generalize the narratives to make them more plausible.

For instance, in UK-SSP1, the participants found the reference to "non-monetary" economy as too extreme, not addressing the transition of the larger economic system and focusing on only a single characteristic of the economy. Thus, the element was reframed to a "well-being" economy, emphasising human well-being instead of GDP growth, and focusing less on monetary values and more on what is good for societal well-being. In UK-SSP2 a reference to crop disease spread was deemed too specific and reframed as a more general series of shocks that could also include human diseases, climate events, energy-related shocks or timber diseases. Furthermore, in UK-SSP2, the Version 1 narrative included a reference to drinking water running out in London. This was deemed unlikely, reconsidered and softened down to a reference to water availability issues. The narrative was softened in UK-SSP4, limiting the references of drug use as one of several descriptors of Generation Alpha and widening it to "dependencies on entertainment". The concluding UK-SSP5 element of "negative environmental tipping points" was also removed as "environmental damages" were seen to be at least partly offset by technology fixes until 2100 where the ending of the narrative was softened to "other solutions are sought to avoid food shortages and maintain living standards".

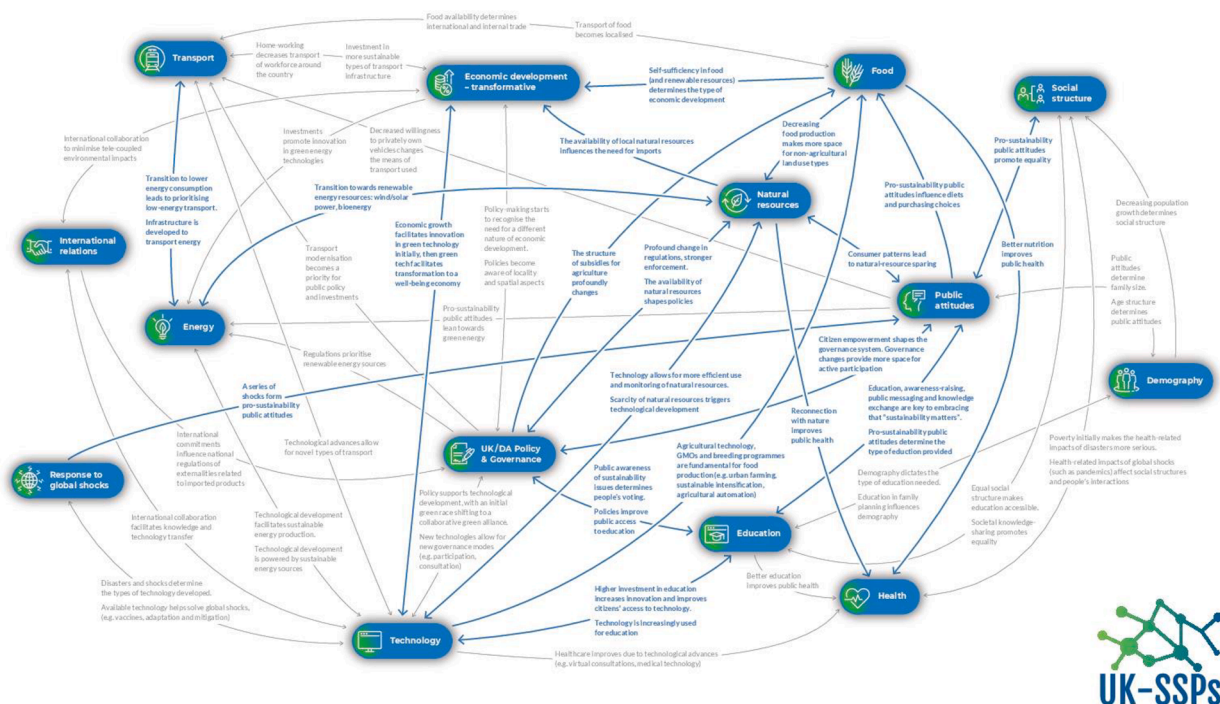


Fig. 2. An illustration of the system diagram visualising the interrelationships between driver categories for UK-SSP1. For a full version of the system diagrams for UK-SSP1-5, please see Supplementary Material C.

3.2.1.5. Adjusting temporal detail. The last broad type of update in the scenario narratives facilitated by the second iteration was changing the timing of specific scenario elements. Some elements were deemed to appear too late in the Version 1 scenarios and were moved to earlier time periods, for example, the start of rapid technological development in UK-SSP1, the shift to payments for ecosystem services in UK-SSP2, or the introduction of new workforce protection due to changing work patterns in UK-SSPs 1 and 2. Other elements were deemed unlikely to happen early on and were moved to the later stages of the scenarios, for example, extensive agricultural innovation and its impacts in UK-SSP2, or the introduction of national service in UK-SSP3, which also became a differentiating element between the four UK nations. In addition, some elements were seen as spanning across the whole narrative instead of a specific time period, e.g. the occurrence of shocks and diseases in UK-SSP2.

3.3. System diagrams

System diagrams, resulting from the additional scenario iteration, helped further elaborate and enrich the relationships between the key 14 driver categories and various scenario elements in each of the UK-SSPs, and thus bring more depth to the scenarios through an additional layer of participatory co-design. Furthermore, they served as a communication means to highlight the bridge between the qualitative narratives and the semi-quantitative trends (see the project website on [Insightmaker](#)).

Each of the resulting system diagrams included the 14 key socioeconomic driver categories (Table 1) as nodes. The interrelationships between the driver categories, specific to each UK-SSP, were depicted as links with labels clarifying the particular meaning of the interrelationship in the given UK-SSP. An illustration of a system diagram for UK-SSP1 is shown in Fig. 2; the complete set of system diagrams is provided in Supplementary Material C. It is important to note that the resulting system diagrams were not intended as system dynamics models. They were rather co-designed as visual representations of the narratives, allowing the participants and potential future users of the scenarios to consider the interrelationships in the scenarios more explicitly. Those links shown in blue in each system diagram were considered particularly important in the development of the logic of the scenario, whilst those links shown in grey support and strengthen the core interrelationships between driver categories. For example, for UK-SSP1 (Fig. 2) a shift to collaborative and pro-sustainability public attitudes is very central to this scenario. This has an effect on many of the different scenario elements, as can be seen by the number of connections emerging from this particular driver category.

For communication and outreach purposes, the system diagram for each UK-SSP was animated and accompanied by a narrated video walk-through, emphasizing its key driver categories (nodes) and their interrelationships (<https://www.ukclimateresilience.org/products-of-the-uk-ssps-project/>). Such presentation aimed to enhance the accessibility and understandability of the systemic connections within each scenario for users.

3.4. Semi-quantitative trends

The final set of socioeconomic indicators and their semi-quantitative trends to 2100 developed in the second iteration consisted of 50 indicators, representing the complexity of the qualitative narratives and aiming to feed into further modelling (Merkle et al., in review). Consequently, the semi-quantitative trends were developed as a transition between the relative, qualitative terms of the scenario narratives and the absolute values required by modelling teams. For that reason, the semi-quantitative trends were deliberately left broad in order to accommodate different model types and to allow for specific translation for each model.

The semi-quantitative trends were represented on a 7-point scale (- - for steep decrease; - for moderate decrease; - for slight decrease; 0 for a stable trend; + for slight increase; ++ for moderate increase; +++ for steep increase). A 7-point scale was applied based on previous experience of the research team that 3 or 5 point scales do not provide the option to sufficiently nuance the trends, while a scale of more than 7 points may feel overwhelming to the participants (Pedde et al., 2021). The semi-quantitative trends were provided to end users rendered as illustrative graphs covering three time periods, with a detailed rationale for each trend (see Supplementary Material D).

Similarly to Version 1 UK-SSPs, Version 2's set of indicators comprised the categories of Society, Technology, Environment, Economy and lifestyles, and Policies and institutions. However, the indicators and their trends were substantially nuanced during the iterative process (see Table 2 for a comparison of the Version 1 and 2 indicators). For instance, the indicator Overall consumption and diet was nuanced into Consumption level, Consumption source/proximity, Meat consumption and Resource and food waste. Furthermore, brand new sets of indicators were introduced, e.g. the Governance-related cluster of indicators was enriched to include semi-quantitative trends in the Effectiveness of institutions, Participation in governance, Devolution and decentralisation of decision-making and Public awareness and engagement.

4. Discussion

The Version 2 UK-SSPs developed in this study demonstrate the added value of multiple iterations in participatory scenario development processes, and contribute to the global effort to increase the usefulness and relevance of global SSPs (van Ruijven et al., 2014). Furthermore, they address the issues of reproducibility, robustness, legitimacy, saliency and consistency of scenarios across scales through designing an iterative process across multiple projects and communities (O'Neill et al., 2020; Rounsevell and Metzger, 2010), while strengthening the collaboration with stakeholders and users of the scenarios.

As outlined in Fig. 1, the second iteration of the scenario co-design process introduced several types of changes to the different scenario products and aided the creation of new ones. First, the scenario products were validated by the stakeholders and adjusted where needed. Second the products were expanded (namely in terms of geographic, temporal and sectoral coverage), and the narrative

Table 2

Extended list of indicators resulting from the second iteration of UK-SSPs as compared to the first iteration.

Version 1 UK-SSPs (Pedde et al. 2021)	Version 2 UK-SSPs
Population	1 Population
	2 Ageing
Mobility	3 Physical mobility
	4 Public transport
Migration	5 Migration
	6 Social mobility
Urbanisation (area and population)	7 Urban population
	8 Urbanisation
NA	9 Education
NA	10 Health investments
NA	11 Health care
Social cohesion/ participation	12 Social cohesion
Human capital	13 Human capital
Social capital	14 Social capital
Tech Development	15 Technological development
	16 Green technology
	17 Tech transfer
	18 Diffusion of tech across society
	19 Infrastructure
	20 Renewables
	21 Bioenergy
	22 Energy efficiency
	24 R&D
Water abstraction change	23 Water abstraction change
Manufactured capital	25 Manufactured capital
Protected areas	26 Protected areas
NA	27 Land use regulation
NA	28 R&D effects on agricultural yields
Arable land	29 Agriculture area
Fertiliser use	30 Fertiliser use
Natural capital	31 Natural capital
GDP per capita	32 GDP
NA	33 Household income per capita
NA	34 Tourism
NA	35 Industry
NA	36 Funding transfers
Inequality	37 Inequality
Overall consumption and diet	38 Consumption level
	39 Consumption source/ proximity
	40 Meat consumption
	41 Resource and food waste
Financial capital	42 Financial capital
NA	43 Imports of natural resources
NA	44 Globalisation of trade
International cooperation	45 International cooperation
Environmental policy	46 Environmental policy
NA	47 Effectiveness of institutions
NA	48 Participation in governance
NA	49 Devolution and decentralisation of decision-making
NA	50 Public awareness and engagement

elements and trends were nuanced and edited where appropriate. In particular, the logic of the initial stages of the scenario narratives was strengthened. Finally, the number of incorporated socioeconomic driver categories and indicators was substantially increased, and a new scenario product, the UK-SSP system diagrams, was developed. As a result, Version 2 UK-SSPs with the additional detail and broader range of scenario products will enhance the utility of the scenarios to climate risk and resilience communities.

In the following sections, we discuss the novelty, advantages and disadvantages of our iterative participatory co-design approach, particularly with respect to its reproducibility and online set-up, from the perspective of the process itself and the scenario products developed.

4.1. Reproducibility of the process

A novel aspect of the scenario co-design approach outlined in this paper is its reproducibility, i.e. possibility to be iterated repeatedly within a given geographical or sectoral context in order to build on previous versions of focal scenarios and develop, validate and enrich them further (Gray et al., 2018; Olazabal et al., 2018). This study illustrated the reproducibility of the approach by

relating its application in an updated online form to the results of its previous application in an in-person set-up, for the context of the UK (Pedde et al. 2021), with the benefits presented in the Results section and discussed below.

The iterations of the reproducible approach allow its users to build on the initial version of SSPs (national or higher-scale) Version 1 and ensure the consistency with their updated version during the co-development process. In our case, this was achieved by two strategies. First, during the co-design process, the participants were invited to brainstorm without constraints (e.g. in the case of the first workshop session, on key socioeconomic drivers) but their input was immediately compared and contrasted with Version 1 UK-SSPs (e.g. its set of key driver categories). Similarities and differences could then be discussed and resolved. Second, the participants were invited to work with and edit the existing Version 1 scenarios, e.g. in the case of the scenario narratives, which were used as a starting point to a series of participatory exercises leading to discussing, editing and enriching the scenarios. As a result of these two strategies, we were able to balance out respecting the boundaries posed by the Version 1 scenarios and providing enough freedom for participatory knowledge co-design, while improving consistency both within the scenarios and across their Version 1 and 2.

In addition, the iterations of the reproducible approach enable scenario builders to involve a more diverse group of stakeholders in the scenario co-design process (Carlsen et al., 2017). While in one-off scenario building, the process is constrained to a single selection of participants and the gaps it is bound to include, the iterative approach can build on the gaps, process and rethink them, and make sure to diversify and enrich the portfolio of participants in the following iterations. This not only diversifies the perspectives included in the final scenarios, but also deepens the collaboration with the stakeholders as well as the knowledge co-production process, thus increasing the legitimacy and utility of the resulting scenarios for practice and decision-making. For instance, a higher representation of the UK devolved administrations in the second-iteration workshop, compared to the first iteration in the scenario-building process, resulted in the reframing of the UK/Devolved Administration policy & governance driver category around its dimensions of level of centralization/devolution, instead of the Version 1 framing around social cohesion and effectiveness, which were incorporated into the updated driver categories of Public attitudes and Social structure.

Finally, the reproducible approach increases the total time available for the co-design of the scenarios across the iterations which can take place across different projects. The time available for the scenario development, together with the aspects described above, enables the participants to substantially improve the internal consistency and logic of the scenarios, as well as to enrich their detail and nuance their elements.

4.2. Online design

This study was based on online stakeholder representation and engagement, which has been rather rare in scenario development hitherto. While the online design of the stakeholder workshop was originally necessitated by the global situation caused by the Covid-19 pandemic and was encumbered by multiple challenges, it also proved to bring a number of benefits. Consequently, here we present lessons learnt regarding which aspects of knowledge co-design were hampered and which were strengthened by the online scenario building set-up.

The key challenge lay in the lack of opportunities for personal interactions and exchanges between the participants, including informal ones. Under normal circumstances, these represent an important added value of an in-person stakeholder workshop. Informal exchanges help stakeholders establish relationships, better understand each other's perspectives and build networks (Jacobs et al., 2009). In the online set-up, these benefits are substantially limited.

On the other hand, the online set-up proved beneficial in terms of democratising the process and enabling all the participants without difference to include their voice equally. In an in-person set-up, different participants approach workshop exercises and exchanges differently and tend to present their opinions with a different strength (Elsawah et al., 2020). As a result, their contributions can be accounted for disproportionately in the final outputs (Honey-Rosés et al., 2020). Although workshop facilitation can substantially contribute to making sure that every-one's voice is being heard equally (Honey-Rosés et al., 2020), this issue still remains rather challenging and may distort the scenario results (Elsawah et al., 2020). On the contrary, in this study, the online set-up of the workshop and its exercises enabled each participant to challenge, edit and elaborate Version 1 UK-SSPs in an inclusive way, since it allowed us to collect input from every single participant, e.g. through polls, eliciting trendlines for key indicators from each participant individually. To this end, further beneficial features of the online set-up were the chat functionality (which enabled us to keep track of all inputs in discussions), and the "raise hand" function of the online interface, structuring the order in which participants contributed to the discussion.

In addition, the online workshop set-up enabled a greater number of stakeholders to participate as costs per stakeholder were considerably reduced. Finally, it ensured participants' continuous engagement throughout the workshop, making the inclusion of individual contributions more transparent and thus building trust in the process. We argue that this does not necessarily have to remain an asset of an online set-up, but can present a lesson learnt also for in-person stakeholder-based scenario workshops.

Another advantage of the online set-up of the workshop was that the project team was able to process intermediate results from the initial stages of the workshop immediately and feed them into subsequent workshop sessions. For instance, the socioeconomic drivers brainstormed in the first session of the workshop could be directly ordered, organized and opposite dimensions could be assigned to them immediately, which enabled the participants to vote on plausible directions of their trends in each UK-SSP in the subsequent session and see their differences emerging live. Another example was compiling each participant's individual trendlines into a single graph in between sessions, so that the aggregated graph could feed in the next session as a starting point to discussing the differences between the trendlines and their rationale, and reaching a consensus. Such exercises allowing the participants to see their input incorporated and visualized in real time were very positively received among the participants.

4.3. Scenario outputs: System diagrams

The introduction of the system diagrams proved a useful addition to traditional participatory scenario-building processes, as it enabled structuring the process of participants' deliberation, as well as the final scenario narratives. This experience was in line with calls in the scenario literature to provide structure to qualitative narratives (van Vliet et al., 2012) to match the challenge of allowing creativity and divergent opinions to emerge consistently with a well-structured process.

Further benefits of scenario system diagrams lie in visualising and identifying inter-relations amongst different driver categories and scenario elements, which can be otherwise easily overlooked, and in increasing the consistency of the narratives. Moreover, the main objective of our system diagrams was to provide a consistent guide to navigate the narrative more interactively than in textual form. In that sense, we place the system diagrams in the category of "visuals" in support of scenario learning and communication as in Vervoort et al. (2010). This resonates with the finding that integrating interactive media in participatory scenario development enables learning and captures complexity more easily (Vervoort et al., 2010) (see also the presentation of the resulting system diagrams on *Insightmaker*).

It is important to note that system diagrams exist in the scenario literature, for example Fuzzy Cognitive Maps, Bayesian Networks and Cross-Impact-Balance approaches to attempt a quantitative systemic mapping of stakeholders' perceptions. However, while undoubtedly strengthening the transparency of the qualitative-quantitative links and creating common understanding amongst stakeholders (de Jong and Kok, 2021), it remains challenging to co-develop these approaches in diverse participatory settings and validation steps for stakeholders' perceptions are still being explored.

4.4. Scenario outputs: Products and outreach

Version 2 UK-SSPs address the call for detailed national and sub-national versions of SSPs by the UK environmental governance actors (see *Supplementary Material A Box S 1*) and UK's devolved governments. Version 2 UK-SSPs thus aim to facilitate future research on UK climate risk and resilience by enabling analysis of how social, economic and political conditions influence the future exposure and vulnerability of UK sectors and the natural environment to climate change, and thus the potential effectiveness of climate change adaptation and mitigation strategies. Providing UK socio-economic scenarios that are consistent with the latest IPCC-community scenario framework ensures that future UK-specific research by the climate resilience community will be consistent with the IPCC process. This further facilitates synthesis of research within the 5-yearly cycle of Climate Change Risk Assessments that are a requirement of the UK Climate Change Act (2008).

The scenario co-design process described in this study strongly emphasised science communication and outreach (Lupia, 2013). To this end, a wide range of communication products was developed to ensure a higher accessibility and embracement of the UK-SSPs by the research, practitioner and policy communities in the UK and beyond. Through a collaboration with a multi-disciplinary consultancy³ a set of scenario factsheets and videos, blog posts, animated versions of the system diagrams, as well as training events was developed to cover the knowledge and information needs of a diversity of stakeholders.⁴

Within this study, we did not have resources to systematically monitor the take-up of the Version 2 UK-SSP products. It is also rather soon after the finalisation of the Version 2 scenarios to see outputs using the products in the academic or grey literature. However, the team have been approached by other projects under the wider umbrella of the UK Climate Resilience programme for further information on utilising the scenarios (e.g. *ClimaCare*,⁵ *OpenCLIM*⁶) and by the UK Met Office to link the products to a climate data portal being developed jointly with ESRI.⁷ These activities provide promising indications of interest and early take-up by target audiences.

5. Conclusions

This study applied a participatory scenario co-design methodology to validate and extend an existing version of the UK-SSPs with additional geographic, sectoral and temporal detail, while maintaining their consistency across scales. It introduced a novel set of UK-SSP Version 2 scenarios, bridging global SSPs with national and sub-national realities.

The iterative approach to scenario building described here brings multiple benefits, including increasing the consistency across scenario drivers and narrative elements, and filling in sectoral and thematic gaps. In addition, it enhances the knowledge co-design process involving a range of stakeholders and researchers in the scenario building, leading to new ways of stakeholder representation and engagement. In particular, the iterative and online set-up of the scenario building facilitated a variety of different ways in which the scenarios were nuanced, detailed and extended.

Collectively, the UK-SSPs Version 2, as a new set of UK socioeconomic scenarios, will facilitate future research on UK climate risk and resilience by enabling analysis of how social, economic and political conditions influence the future exposure and vulnerability of UK sectors and the natural environment to climate change, and thus the potential effectiveness of climate change adaptation and mitigation strategies. For the global audience, they can serve as a methodological baseline for improving the regional applicability of

³ Countryscape (<https://countryscape.org/>).

⁴ <https://www.ukclimateresilience.org/products-of-the-uk-ssps-project/>.

⁵ <https://www.ukclimateresilience.org/projects/climacare-governing-the-climate-adaptation-of-care-settings/>.

⁶ <https://www.ukclimateresilience.org/projects/openclim-open-climate-impacts-modelling-framework/>.

⁷ <https://www.esri.com>.

the global SSPs, as well as a means of comparison with other regional, national and sub-national SSP-based scenario sets.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.crm.2022.100452>.

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