UK-SSPs

User Manual

Development & provision of UK socioeconomic scenarios for climate vulnerability, impact, adaptation & services research & policy (UK-SSPs)

May 2021

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This work is funded by the Met Office via the Strategic Priorities Fund (SPF). All views expressed within this report, and any errors contained therein, are the responsibility of the Consortium.

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1 Introduction

1.1 How the UK-SSPs should be interpreted

How are scenarios used in climate change research?

The future is inherently uncertain. Scenario modelling involves examining a range of possible futures, instead of attempting to predict just one single future. A particular scenario does not usually represent a complete description of the future, instead it focuses on key drivers affecting future developments. In climate risk and resilience research it is important to consider both future scenarios for the climate and the economy, since both affect our society's ability to manage and cope with climate risks. The global SSP scenario framework is the most recent and commonly used scenario framework in climate change research.

The global SSPs, used in IPCC assessments, are five different storylines of future socioeconomic circumstances, explaining how the global economy and society might evolve over the next 80 years. Crucially, the global SSPs are independent of climate change and climate change policy, i.e., they do not consider the potential impact climate change has on societal and economic choices.

Instead, they are designed to be coupled with a set of future climate scenarios, the Representative Concentration Pathways or 'RCPs'. When combined within climate research (in any potential combination), the SSPs and RCPs can tell us how feasible it would be to achieve different levels of climate change mitigation, and what challenges to climate change mitigation and adaptation might exist.

The UK-SSPs project

Previously, no UK-specific versions of the global SSPs were publicly available to combine with the RCP-based climate projections. However, the 'Development & provision of UK socioeconomic scenarios for climate vulnerability, impact, adaptation & services research & policy' (UK-SSPs) project has filled this gap by developing a set of socioeconomic scenarios for the UK that are consistent with the global SSPs used by the IPCC community, and which provide the basis for further UK research on climate risk and resilience. The project was commissioned by the Met Office and was funded by the UK Climate Resilience Programme. It was carried out by Cambridge Econometrics in collaboration with the UK Centre for Ecology & Hydrology (UKCEH), University of Edinburgh and University of Exeter.

Four products have been produced from this project that will provide major benefits for future research into UK climate risk and resilience: (i) narratives for all five SSPs for the UK and its countries that have been regionally, sectorally and temporally extended from the global SSPs; (ii) tables of semi-quantitative trends for a wide range of socioeconomic indicators; (iii) quantified projections for specific indicators at the appropriate temporal and spatial resolution (ranging from a 1km grid to the whole of the UK); and (iv) a set of system diagrams that visualise and quantify the interrelationships between the key drivers represented in the scenarios and ensure internal consistency in their future projections, enabling the UK research community to add new variables or quantifications in the future.

Independence from climate change and climate policy

Like the global SSPs, in the UK-SSPs the economy and society are independent from and therefore not influenced by climate change. This is because the UK-SSPs explore how economic and societal choices will affect greenhouse gas emissions and, how feasible it is to meet climate targets such as the goals of the Paris Agreement. It is therefore imperative that no assumptions are made about climate change, and the impact this has on society.

Similarly, and in line with the characteristics of the global SSPs, the UK-SSPs are independent of climate change policy. Essentially, the SSPs represent five *baseline* scenarios in which socioeconomic factors such as population, economic growth and technological development could lead to very different future climate outcomes, *even without* climate policy. It is important to note that the UK-SSPs do not assume futures with no governance, rather, the scenarios demonstrate the extent to which socioeconomic factors are the drivers of change, rather than policy. This allows researchers to look at how underlying socioeconomic conditions pose challenges or opportunities for the implementation of climate policy.

Why was it so important for UK-specific SSPs to be produced?

The UK-SSPs provide a consistent starting point for differing analyses of the climate risks facing the UK. In addition, by providing the UK research community with scenarios that are consistent with the IPCC process, this ensures that subsequent research is fully compatible with the IPCC 6th Assessment Report and future IPCC assessments.

More generally, it is now clearer than ever that there are numerous possible futures, and great uncertainty, when considering what impact our society and economy might have on the potential for curbing emissions and climate change impacts in the future. This has implications for the adaptations we need to plan to manage climate risks that cannot be mitigated.

The UK-SSPs acknowledge that the economy and society can diverge quite substantially from historical trends, and it is the storylines behind those divergences which they seek to explain and quantify.

1.2 The purpose of this document

This document details the methodologies applied within the UK-SSPs project funded by the UKCR Programme. It provides information on the data and information sources used and the approach taken to produce each of the products produced by the UK-SSPs project (and listed above). It also details the checks carried out throughout the project as part of quality assurance.

Structure of the remainder of the report

The rest of this report is structured as follows:

- Chapter 2 provides the approach taken to produce the UK-SSP scenario narratives and systems diagrams.
- Chapter 3 details the approach applied to construct semi-quantitative trends for 50 socioeconomic indicators.
- Chapter 4 provides details about the data sources used and the various methodologies applied to construct the quantified projections of selected socioeconomic indicators.
- Chapter 5 provides an overview of the quality assurance checks carried out throughout the project.

- Chapter 6 concludes with some guidance on how the various UK-SSP products can be used together, and in what sort of analyses they can be applied.

2 Methodology for producing scenario narratives & systems diagrams

2.1 Introduction

In this chapter, we provide an overview of the methodology that was implemented to co-create the UK-SSP narratives and system diagrams with a wide range of stakeholders and experts.

Our approach involves downscaling and extending the full set of five Shared Socio-economic Pathways (SSPs) for the UK to support more detailed analyses of climate risk and resilience. Three types of extensions have been undertaken:

- Spatial extensions: the global and European SSPs were used to contextualise regional scenario development for the UK and its four constituent countries (England, Wales, Scotland and Northern Ireland).
- Temporal extensions: the global SSPs describe only general trends for the 21st century. Temporal extensions have been embedded within the spatial extensions to provide additional detail on relevant temporal aspects and how sequential events may arise over time from today until 2100.
- Sectoral extensions: the global SSPs provide only broad indications on sectoral developments. These have been expanded within the downscaled SSPs for the UK and its four countries.

2.2 Building on the UK-SSP narratives from the UK-SCAPE project

The UKCEH National Capability project UK-SCAPE has been developing downscaled versions of the SSPs for the UK as a whole (https://www.ceh.ac.uk/uk-scape/speed-spatially-explicit-projections-environmental-drivers-and-impacts). These UK-SSPs were co-produced with a wide range of stakeholders through a facilitated 2-day stakeholder workshop in November 2018, followed by analysis by the research team and cross-checking of this analysis using two questionnaires. The participatory process engaged with stakeholders involved in research, policy, NGOs and the private sector, and with a diversity of sectoral/disciplinary expertise. The process involved the identification of driving forces of change and their uncertainties specific to the UK context and mapping them to the global and European SSPs (the latter from the EU-funded IMPRESSIONS project, Kok et al. 2019). Workshop participants then elaborated a narrative of each UK-SSP and agreed semi-quantitative trends over the 21st century in nine specific socio-economic variables. Based on discussions at the workshop and other data sources, the research team then further elaborated the narratives and developed tables of trends for a wider list of socio-economic variables.

The UK-SSPs narratives from UK-SCAPE consist of approximately 2-page descriptions of how socio-economic developments in the UK could evolve between now and 2100 based on assumptions that are consistent with the global (O’Neill et al. 2015) and European (Kok et al. 2019) SSPs. The narrative for each UK-SSP consists of an abstract, a storyline of socio-economic development for three time periods (present to 2040; 2041 to 2070; and 2071 to 2100), and short paragraphs that pull out key developments for the main land use sectors (agriculture, forestry, biodiversity, urban, water), health and energy. Further details about the method and products for the UK-SSPs produced by the UK-SCAPE project are given in Pedde et al. (2020).

The UK-SSPs narratives developed through the UK-SCAPE project were the starting point for this project, as they were already fully consistent with the global and European SSPs. Our method provides further cross-checking of the key socio-economic driving forces of change, their uncertainties for the UK and how they map to the global and European SSPs. It also further extends them temporally, sectorally and spatially; the latter into a consistent set of country-specific SSPs for England, Wales, Scotland and Northern Ireland. Finally, our method adds further detail on the interrelationships between socio-economic driving forces within the UK-SSPs by creating systems diagrams.

2.3 Stakeholder workshop

A stakeholder workshop was organised to extend and enrich the UK-SSPs from the UK-SCAPE project. This was originally planned as a 2-day physical workshop, but was redesigned as a 4-day online workshop, with two 1.5-hour sessions per day, due to coronavirus restrictions. Participants were selected to ensure representative coverage of a broad range of expertise and viewpoints across the UK climate resilience community. Categories for stakeholder selection were agreed with the Met Office to include (i) both societal (institutional, NGOs, private sector) and scientific expertise (academics); (ii) a diversity of sectoral or disciplinary expertise (e.g. urban/built environment, agriculture, forestry, biodiversity, water, flooding, coasts, health, transport, infrastructure, energy, climate, economics/trade, technology, policy/governance, lifestyles/behaviour and social sciences); and (iii) several individual and geographic characteristics to enhance diversity and broader inclusion (e.g. age, gender, UK country). Participants who attended the previous UK-SCAPE stakeholder workshop held in November 2018 were also included to ensure cohesion and memory from this previous work. This led to a long list of more than 200 stakeholders. A subset of 120 stakeholders covering the different categories were selected to invite to the workshop.

The online workshop was held on 4-7 May 2020 involving 37 stakeholders from academia, policy, practice and business. The workshop was designed and professionally facilitated to be highly interactive in order to stimulate lively discussions while guaranteeing coherence of the overall process. Plenary and breakout group sessions were alternated to bring together expert and local knowledge, viewpoints and insights for each of the five SSPs, whilst maintaining consistency between the content of the UK-SSP narratives with the European/global SSPs. The eight workshop sessions covered:

- SESSION 1: Plenary session for all participants:
  - **a)** Welcome and introductions to the online workshop and participants
  - **b)** Identifying and clustering UK socio-economic drivers and uncertainties
- SESSION 2: Plenary session for all participants:
  - **c)** Introduction to the Shared Socio-economic Pathways (SSPs)

   d) Mapping UK drivers and uncertainties to the SSPs
- SESSION 3: Breakout groups per SSP:
   e) Elaborating UK and country-specific storylines in breakout groups
- SESSION 4: Breakout groups per SSP:
   f) Creating systems diagrams to understand the interrelationships between drivers in the storylines
- SESSION 5: Plenary session for all participants:
   g) Tour of UK-SSPs covering work done in SSP breakout groups in Sessions 3 and 4
   h) Gathering feedback from participants
- SESSION 6: Breakout groups per SSP:
   i) Refining and expanding UK and country-specific storylines based on feedback from Session 5
- SESSION 7: Breakout groups per SSP:
   j) Developing semi-quantitative trends for specific variables for the storylines
- SESSION 8: SSP breakout groups followed by plenary:
   k) Consolidating semi-quantitative trends for specific variables for the storylines
   l) Next steps, wrap-up and closing remarks.

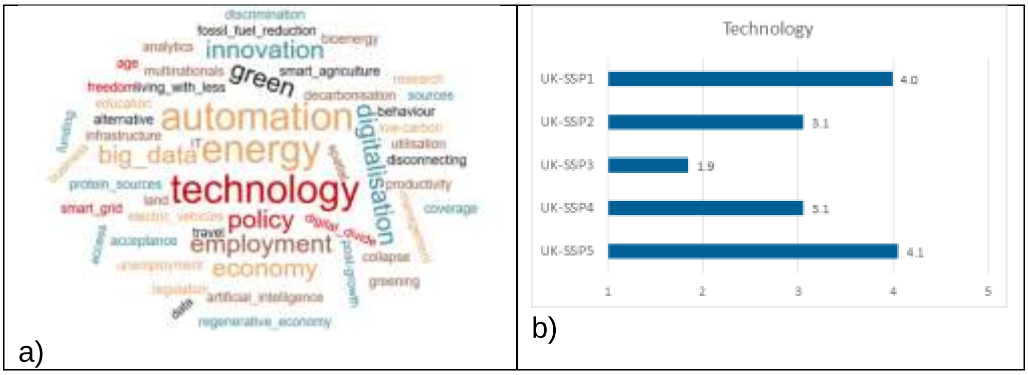
The online workshop produced a vast amount of insightful input from stakeholders for enriching the UK-SCAPE UK-SSP narratives and creating new system diagrams depicting the interrelationships between drivers within each UK-SSP. The first two sessions focused on participatory identification and clustering of socio-economic drivers that were considered to be particularly important and uncertain for determining the socio-economic development of the UK over this century. The participants identified over 700 specific drivers, which were clustered into 14 final driver categories (Table 2.1). Detailed suggestions were made by stakeholders about the different dimensions of each driver category that were portrayed as Word Clouds (see Figure 2.1a for an example). In between the workshop sessions, each driver category was analysed by the project team to determine their specific polarities (extreme dimensions) (Table 2.1). The participants then scored where they thought each SSP would sit between the extreme polarities of each driver category for the UK (see Figure 2.1b for an example). The complete set of the Word Clouds capturing the dimensions of all driver categories and the scoring of the trends in these drivers for each UK-SSP is summarised in Harrison et al. (2020).

Table 2.1 The 14 driver categories identified by workshop participants and their polarities (extreme dimensions).

Driver category	Polarity 1	Polarity 2
UK/DA policy & governance	Devolved	Centralised
International relations	Protectionist	Globalised

Economic development	Traditional market-based systems	Novel economic systems
Social structure	Privileged, few	Egalitarian, many
Public attitudes	Disillusioned, disengaged & disempowered	Engaged, empowered & inspired
Demography	Lower proportion of people aged over 65	Higher proportion of people aged over 65
Technology	Slow development	Rapid development
Natural resources	Resource-friendly, sustainable use	Resource over-exploitative, unsustainable use
Food	Low meat diet	High meat diet
Energy	Low carbon	High carbon
Education	Low investment	High investment
Health	Low investment	High investment
Transport & mobility	Low mobility	High mobility
Response to global shocks	Persistence	Transformative change

Figure 2.1 Example Word Cloud for the Technology driver category (a), and its scoring (b)



Note(s): for this driver, the scale ranges between the polarities of Slow (value 1) and Rapid (value 5). The values represent a weighted mean score of 37 workshop participants and 10 members of the project team.

Information from all sessions of the online workshop was cleaned and processed by the research team to check the coverage of the 14 key socio-economic driver categories throughout the UK-SSP narratives, and the consistency across the five UK-SSPs in terms of both content and presentation for the narratives and systems diagrams. This resulted in a set of draft full narratives of approximately 4 to 5 pages in length (abstract, detailed description of the scenario development in three time periods: present to 2040; 2040 to 2070; 2070 to 2100, followed by four country paragraphs that build on the full narrative, emphasising differences of each UK country from the full narrative or providing specific regional examples) and a set of systems diagrams for the five UK-SSPs. We also identified gaps in coverage, which we could then address through targeted semi-structured interviews and a questionnaire.

2.4 Semi-structured interviews

The main gap identified in the draft narratives produced after analysis of the information from the stakeholder workshop was in terms of country-specific detail. Hence, seven semi-structured interviews were organised during August and September 2020 covering England, Wales, Scotland and Northern Ireland. The interviews covered a range of questions where further enrichment at the country level would be useful, such as in each nation how might devolved governance develop, how might changes in social structure and public attitudes emerge, which economic activities, energy sources, natural resources and land uses might be prioritised, and how might relationships between the nations develop. Following the interviews, the research team processed the responses from the interviewees and used the additional information to further extend the draft narratives, particularly the country paragraphs, leading to full narratives of approximately 5 to 6 pages.

2.5 Questionnaire

Near final narratives were created following the semi-structured interviews. These were sent to 34 stakeholders who participated in the workshop sessions and semi-structured interviews on the narratives to ensure that we had correctly interpreted and elaborated their local and expert knowledge using a questionnaire. The questionnaire asked participants whether the narrative reflects the discussions during the workshop (on a scale between 1 for not at all and 5 for fully). In addition, several multiple-choice questions were included to get feedback on selected elements of the narratives. These questions differed for each narrative; for instance, for SSP1, they were targeted on the expected extent of food and material imports, and the envisioned type of animal production. Finally, we asked whether the references to particular places or regions in the narratives represent reasonable illustrations. In addition, the respondents 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, e.g., confirming that in UK-SSP1 animal production is more likely to be integrated in mixed agricultural systems than to be concentrated in specialised farms. 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.

The project team used the feedback from the stakeholder questionnaire to refine and finalise the narratives and systems diagrams that are available from https://www.ukclimateresilience.org/products-of-the-uk-ssps-project/.

3 Methodology for forming semi-quantified trends

3.1 Introduction

In this chapter, we provide an overview of the method that was implemented to develop semi-quantitative trends consistent with the UK-SSP narratives and system diagrams. The trends provide a bridge between the complexity of the narratives and the needs of quantitative modellers for parameterised impact models.

Two steps were involved in the development of the semi-quantitative trends:

1. Eliciting trends for seven socio-economic variables through a co-creation process in the stakeholder workshop.
2. Building and harmonizing a master table of 50 socio-economic variables and their definitions, including the trends elicited in the workshop with additional variables (i) from the global SSP database; (ii) from the UK-SCAPE project's semi-quantitative trends for the UK-SSPs; (iii) recommended by the User Panel and Activity 3; and (iv) that enable good coverage of the 14 key driver categories identified by stakeholders as being particularly important and uncertain for determining the socio-economic development of the UK over this century in the stakeholder workshop (see Chapter 2).

3.2 Elicitation of variable trends in co-production with workshop participants

The online stakeholder workshop described in Chapter 2 was designed to alternative plenary and breakouts sessions such that stakeholders gradually became increasingly familiar with the UK-SSP narratives enabling them to contribute in greater depth and detail as the sessions unfolded. As the elicitation of semi-quantitative trends requires this in-depth knowledge of a specific UK-SSP, the two sessions focused on this activity were positioned at the end of the workshop (Sessions 7 and 8). In these sessions, stakeholders were asked first to draw individual semi-quantitative trends for specific variables for the storylines, and then asked to discuss their individual trends to create a consensus trend per variable.

The seven variables were selected prior to the workshop taking account of several criteria: (i) variables were broad enough to be understandable so that they could be discussed by stakeholder groups with different backgrounds; (ii), variables were useful and relevant to the quantitative spatial projections being developed; (iii) historical data was available for the variable that could be used as a reference for stakeholders; and (iv) variables complemented those for which trends were created in the UK-SCAPE project stakeholder workshop held in November 2018 (Pedde et al. 2020). The UK-SCAPE stakeholder workshop considered nine variables:

- Change in the extent of arable land
- Change in fertiliser use

- Change in water abstraction
- Change in protected areas for biodiversity
- Change in the five capitals (human, social, manufactured, financial and natural).

Based on these criteria, the final selection of socio-economic variable for the online stakeholder workshop was:

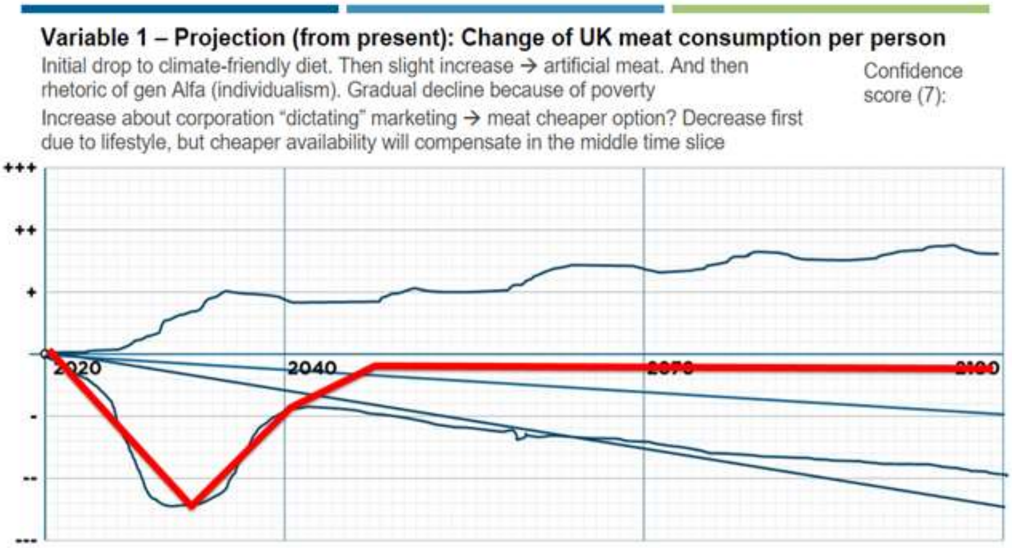
1. Change in UK meat consumption per person
2. Change in UK availability of health services per capita
3. Change in UK public spending on infrastructure relative to the size of the economy
4. Change in UK spending on R&D relative to the size of the economy
5. Change in the level of globalisation of the UK economy
6. Change in the share of bioenergy within the total energy mix in the UK
7. Change in the transfer of public money from England to other UK countries.

The elicitation approach for each variable was inspired by the Fuzzy Sets method (Pedde et al. 2018) and divides the workshop process into two parts. Session 7 allowed stakeholders to provide first individual input and express their reasoning for this input. This involved asking stakeholders to download a pre-prepared PowerPoint slide pack containing historic trends and graph templates for each variable. Stakeholders were then asked to draw their own individual trendlines based on a description of the variable by the group facilitator without discussion or being able to see the trendlines of other participants. After Session 7 the participants submitted their PowerPoint slide packs and the research team overlaid them onto a single graph per variable for each UK-SSP. In Session 8 these consolidated graphs were presented to all stakeholders in the UK-SSP breakout group to initiate a discussion aimed at achieving joint agreement on both a consensus trendline and a rationale for the consensus trendline.

An example of the output from Sessions 7 and 8 is provided in Figure 3.1. This shows the y-axis of the graphs covered seven classes: strong, moderate or small decrease, no change, and small, moderate or strong increase in the variable compared to present. The x-axis covered the three time periods of the narratives: present to 2040; 2040 to 2070; and 2070 to 2100.

In addition to a rationale for their trendline, stakeholders were asked to provide a confidence number ranging from 0 (lowest confidence) to 10 (highest confidence), to capture the confidence that they had when defining the semi-quantitative trendline of the variable for their scenario. The confidence scores were used as part of the assessment of the participatory exercise, as well as to check the internal consistency of the scenarios (from the stakeholder's point of view).

Figure 3.1 Example of a semi-quantitative trend developed in Sessions 7 and 8 of the online stakeholder workshop



Note(s): Blue lines: individual trends, developed in Session 7. Red line: the consensus trend, developed in Session 8. Both a qualitative description and a confidence score are captured as well to understand the logic of the trend.

3.3 Building and harmonising a master table of semi-quantitative trends

The semi-quantitative trends for the seven variables co-created at the stakeholder workshop were further complemented with additional variables. These were selected from three sources:

1. Projections from the global SSP scenario database (specifically for population and GDP);
2. Nine variable trends co-created with stakeholders and an additional 11 variable trends created by expert interpretation of the UK-SSP narratives in the UK-SCAPE project (Pedde et al. 2020);
3. Consultations with the User Panel and project team members to understand requirements regarding variables that would be useful for modelling.

The variable trends obtained from (1) and (2) were consistency checked against the final narratives and systems diagrams. Small adjustments were made to trends from the UK-SCAPE project (Pedde et al. 2020) to reflect slight changes of emphasis in the extensions of the UK-SSP narratives agreed by stakeholders as part of the participatory process.

The 29 variables resulting from the online workshop and other sources were then mapped against the 14 key socio-economic drivers identified by stakeholders as being particularly important and uncertain for determining the socio-economic development of the UK over this century in the stakeholder workshop (see Chapter 2). In addition, they were mapped against the STEEP (Society, Technology, Economy & Lifestyle, Environment and Policy & Institutions) drivers of change used in numerous scenario exercises. Both mappings were used to identify additional variables that improved coverage across the different driver categories that may be useful for the climate risk and resilience modelling community.

This resulted in a final master table of 50 socio-economic variables. For each variable, a semi-quantitative trend was developed by the project team for the five UK-SSPs and three time periods (present to 2040, 2040 to 2070, 2070 to 2100), through a synthesis and harmonization of information derived from the stakeholder workshop, the UK-SSP narratives, the UK-SCAPE project, and the global SSP database. A key part of this process was ensuring internal consistency of the semi-quantitative trends across the products created within the UK-SSP project.

4 Methodologies for forming quantified projections of socioeconomic indicators

4.1 Introduction

In this Chapter, we provide an overview of the methodologies that were applied to form quantified projections of socioeconomic indicators. The process involved three main tasks;

- Selection of indicators
- Identification and collection of relevant data
- Quantification of projections

4.2 Guiding principles for forming quantified projections

A number of high-level principles were adopted to develop the projections. They are;

- Use of the best available historical data. Data sources were chosen based on recency, spatial disaggregation, and credibility. Official UK data sources such as ONS were used where possible.
- Methodological soundness. Models and algorithms for adjustments and downscaling were chosen and designed in iterative processes and with the objective to ensure the best quality of results within the scope of the project.
- Consistency with global SSPs. IIASA projection data for the UK was used to guide the projections and all indicators are either fully consistent with IIASA data, or at least partially consistent when IIASA projections had to be interpolated with the historical baseline in order to ensure credible trends in the early time slices of the projection.
- Consistency with the UK-SSP narratives and semi-quantitative trends. Preliminary quantification results were iterated multiple times within the research team to define parameters and adjustments in a way that ensures internal consistency.

4.3 Indicator selection process

Socioeconomic indicators to be quantified were selected on the basis of input from the UK-SSP User Panel meetings, the stakeholder workshop in May 2020, consultation with the Met Office and Advisory Group, and availability of recent, disaggregated and credible baseline data.

Indicators were categorised into two priority groups reflecting stakeholder interest. First priority indicators were indicators defined as ‘must haves’ by the user panel and/or were mentioned more than once as desired quantitative indicators in the stakeholder workshop. Second priority indicators were defined as ‘desired’ by the user panel and/or were mentioned only once as desired in the stakeholder workshop, and/or were required as inputs to the land-use model.

Table 4.1 provides an overview of quantified indicators.

Table 4.1 Overview of indicators

Indicator	Data source	Scenarios being used	Data dimensions	Metric	Limitations
First Priority					
Population	ONS, 2019 ONS, 2018 Worldpop, 2020 IIASA, 2018	Five SSPs based on IIASA projections	Decadal, 1km grid	Headcount	Dependency on IIASA data, 2020 baseline year assumption
Demography	ONS, 2019 ONS, 2018 IIASA, 2018	Five SSPs based on IIASA projections	Decadal, by age class, LAD	1000 inhabitants	Dependency on IIASA data, 2020 baseline year assumption
Health	ONS, 2018	Five SSPs, central projection trend derived from narrative	Decadal, Local Authority Districts	Life expectancy [years]	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Healthcare	UK regional workforce statistics, 2019 - 2020	Five SSPs, central projection trend derived from narrative e	Decadal, NUTS 2	GPs per capita	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Inequality	OECD, 2011	Five SSPs, central projection trend derived from narrative	Decadal, NUTS 3(based on NUTS 1)	S80/S20 Income Quintile Ratio	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
GDP	ONS, 2019 IIASA, 2018	Five SSPs based on IIASA projections	Yearly, UK aggregate	£2018 million	Dependency on IIASA data (very high values in SSP5), 2020 baseline year assumption

GVA	ONS, 2019	Five SSPs based on GDP projections	Yearly, by economic sector, Local Authority Districts	£2018 million	Dependency on IIASA data (very high values in SSP5), 2020 baseline year assumption
Food Consumption & Net Imports	FAO, 2019	Five SSPs, PLUM model	Yearly, 79 commodities, UK aggregate	Mt per commodity	Relative proportions of commodities within each of the 10 commodity group are fixed
Employment	BRES, 2019 OBR, 2018	Five SSPs based on GVA projections	Yearly, by economic sector, Local Authority Districts	Number of jobs	Dependency on IIASA data (very high values in SSP5), Productivity rate assumed to remain constant across SSPs, 2020 baseline year assumption
Household Income	ONS, 2020 ONS, 2019	Five SSPs based on GVA projections	Yearly, Local Authority District	£2018 million	Dependency on IIASA data (very high values in SSP5)
Food Production		SSP-RCP combinations, CRAFTY agent-based land use model	1km grid (food crops, fodder crops, grass-fed red meat, grass-fed milk), UK aggregate food production index	Quantity index	Challenge of deriving land productivity responses to climate change
Land Use	LCM 2015	SSP-RCP combinations, CRAFTY agent-based land use model	1km grid	Land use classes	Challenge of deriving land productivity responses to climate change (natural capital) Challenge of deriving spatially-variable capital maps (social, human, infrastructure, financial, natural)
Emissions	E3ME-FTT scenarios, IIASA	Five SSPs, based on E3ME-FTT and IIASA GDP projection	Decadal, UK total	Mt CO2	Dependency on IIASA projection and E3ME-FTT low, medium and high carbon scenarios

Technological Development	E3ME-FTT scenarios	Three main low, medium, high carbon scenarios based on E3ME-FTT model	Decadal, UK four sectors	Technological development indicator	Dependency on E3ME-FTT low, medium and high carbon scenarios
Energy	E3ME-FTT scenarios, IIASA	Five SSPs, based on E3ME-FTT and IIASA GDP projection	Decadal, UK total	Primary energy (PJ)	Dependency on IIASA projection and E3ME-FTT low, medium and high carbon scenarios
Electricity	E3ME-FTT scenarios, IIASA	Five SSPs, based on E3ME-FTT and IIASA GDP projection	Decadal, UK by technology	Electricity (GWh)	Dependency on IIASA projection and E3ME-FTT low, medium and high carbon scenarios
Values / Attitudes re Environment	UKHLS, 2013	Five SSPs, central projection trend derived from narrative	Decadal, NUTS 3	% of people with pro-environmental lifestyles	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Second Priority					
Regional Development Transfers	ONS, 2017	Five SSPs, central projection trend derived from narrative	Decadal, England	Fiscal transfers from England [£ 2018 per capita]	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Road Infrastructure	GRIP, 2015	Five SSPs, central projection trend derived from narrative	Decadal, Local Authority Districts	Speed-weighted km/km^2	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Rail Infrastructure	WFP, 2014	Five SSPs, central projection trend derived from narrative	Decadal, Local Authority Districts	m/km^2	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence

R&D Expenses	Eurostat, 2018	Five SSPs, central projection trend derived from narrative	Decadal, NUTS 2	£ 2018/capita	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Education	Eurostat, 2019	Five SSPs, central projection trend derived from narrative	Decadal, LAD (based on NUTS 2)	% of population aged 25-64 with tertiary education	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Social Cohesion	UKHLS, 2015	Five SSPs, central projection trend derived from narrative	Decadal, NUTS 3	% of population with neighbours who are willing to help	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Produced Capital	Eurostat, 2017	Five SSPs, central projection trend derived from narrative	Decadal, LAD (based on NUTS 2)	Gross Fixed Capital Formation per Area [£m 2018/km^2]	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Capital Availability (Savings)	UKHLS, 2017	Five SSPs, central projection trend derived from narrative	Decadal, NUTS 3	% of population able to “save any amount” of their income	Stakeholder process limitations, 2020 baseline year assumption, judgement-based setting of boundaries using best available evidence
Urbanisation	LCM, 2015	Five SSPs, central projection trend from dIAP	Decadal, 1km grid	Presence or absence of artificial surface	Dependency on IIASA data, judgement-based sprawl parameters
Land use intensity	LCM, 2015	SSP-RCP combinations, CRAFTY agent-based land use model	Decadal, UK	Intensity Index	Climate scenario dependency

4.4 IIASA Dependency

A central requirement from stakeholders was to ensure consistency with the global SSPs. For the quantifications this meant following IIASA data for the aggregate UK GDP as well as population. This data is partly inconsistent with the storylines (e.g., growing GDP in SSP3 and massive population and GDP growth in SSP5). Variables impacted by IIASA GDP and population inputs are: Urbanisation, Income, GVA, Employment, Emissions, Energy, and Electricity.

4.5 Specific methodologies applied to each socioeconomic indicator

Introduction

For each indicator the most recent suitable historical data was used as a baseline for 2020. We then applied outputs from suitable models to create projections until 2100 for each SSP. The models used include state of the art integrated assessment models, an environment- and technology-extended macro-econometric model, a novel agent-based model for land use, and a land system modular model for food. Where modelled outputs are not available, trends were derived from the stakeholder process.

Spatial Boundaries and Coordinate Reference Systems

- Indicators quantified at 1km resolution were masked according to the 1km resolution LCM 2015 map (UK Land Cover Map – UK Centre for Ecology & Hydrology (ceh.ac.uk)) and based on the following grid proj4string: "+proj=tmerc +lat_0=49 +lon_0=-2 +k=0.9996012717 +x_0=400000 +y_0=-100000 +a=6377563.396 +rf=299.324975315035 +units=m +no_defs"
- For indicators quantified at LAD resolution, full extent shapefiles from December 2019 were used (UK LAD BFE – ONS (geoportal.statistics.gov.uk)).
- For indicators quantified at NUTS 3 resolution, full extent shapefiles from January 2018 were used (UK NUTS 3 Full Extent – ONS (geoportal.statistics.gov.uk)).
- For indicators quantified at NUTS 2 resolution, full extent shapefiles from January 2018 were used (UK NUTS 2 Full Extent – ONS (geoportal.statistics.gov.uk)).
- For indicators quantified at NUTS 1 resolution full extent shapefiles from January 2018 were used (UK NUTS 1 Full Extent – ONS (geoportal.statistics.gov.uk)).

Projections based on trends from Impressions dIAP

dIAP is a dynamic integrated assessment platform created as part of the EU IMPRESSIONS project (highendsolutions.eu). This web-based modelling platform links several meta-models together to assess climate change and socio-economic change impacts on e.g., the land sector, the water sector, biodiversity and urban development (Holman et al., 2017).

Urbanisation

- The baseline was created with the LCM 2015 map, using an aggregation of urban and suburban land cover to form a baseline map of artificial surface. For urban and suburban land cover and aggregate both categories to a single artificial surface category.
- Projections were created using artificial surface growth trends from dIAP and applying a downscaling algorithm that takes scenario-specific sprawl parameters into account. The process consisted of nine steps:

1) Creation of baseline maps for each scenario, with masks for protected areas and flood risk areas where it matches the narrative.
2) Creation and analysis of 37 dIAP runs with different parameter settings in order to find the best UK-SSP narrative consistent parameter setting.
3) Definition of an SSP2 interpolation between SSP1 and 3, based on IIASA GDP and population data.This step is needed because the currently available version of dIAP does not include any SSP2 projections.
4) Definition of a neighbourhood function with parameters for urban sprawl to allocate new urban pixels in every scenario.
5) Remapping of dIAP growth in artificial surface data from the 10’ output grid to local authority districts.
6) Application of local authority district level artificial surface growth to the baseline map and allocation of new urban pixels according to the neighbourhood function.
7) Allocation checks and corrections where necessary.
8) Repetition for each time step.
9) Checking and plotting of results.

- The resulting density of artificial surface for each SSP was used as an input in other quantified projections, when a separated treatment of rural and urban areas was necessary. Areas were considered “urban” when the share of artificial surface within them was at least as high as a defined threshold:
  - 24% threshold in case of Local Authority District areas
  - 19% threshold in case of NUTS 3 areas
  - 13% threshold in case of NUTS 2 areas
- These thresholds were chosen in accordance with the assumption that 5.9% of UK land surface is covered with artificial surface in the baseline (LCM 2015).

Projections based on trends from the IIASA database

The IIASA SSP database provides quantitative projections of Shared Socioeconomic Pathways and the related Integrated Assessment scenarios for numerous regions. In order to ensure consistency with global SSPs, the IIASA SSPs database was used as the main source of data to produce projections of population, gross domestic product (GDP), gross value added (GVA), employment and household income. In particular, the IIASA SSPs database provides UK level projections of population and GDP. Projections of GVA, employment and household income were then derived from GDP trends.

Population & Demographics

Population and Demographics projections were first created at Local Authority District level and then downscaled to a 1 sq km grid.

- LAD level projections:
  - The baseline is based on the ONS population estimates from 2018 (Estimates of the population for the UK, England and Wales, Scotland and Northern Ireland - Office for National Statistics (ons.gov.uk)), available at the Local Authority District level.

- Projections were calculated using population projections provided by IIASA for each SSP at the UK level and for 19 age bands. Linear interpolation was used between 2019 ONS data (Estimates of the population for the UK, England and Wales, Scotland and Northern Ireland - Office for National Statistics (ons.gov.uk)) and 2030 IIASA estimates (SSP Database (iiasa.ac.at)), to produce projections between 2020 and 2030. Population projections over the period 2030-2100 are fully consistent with the IIASA projections.
- Population projections at Local Authority District level are calculated using subnational shares derived from ONS 2018-based population projections (Population projections - Office for National Statistics).
- Consistency checks against UK-SSP narratives were carried out and a set of parameters for regional adjustment (convergence, divergence, and rural/urban adjustments) was identified. Regional adjustments were then implemented in order to match the narratives.

- Downscaling to 1km grid:
  - The baseline was created from the UK constrained top-down estimated population data for 2020 (United Kingdom Population 2020 – WorldPop (worldpop.org)). Values were aggregated to the 1km grid, the map was masked with the LCM 2015, and values were rescaled in order to match the LAD level baseline.
  - Downscaled projections were created in three steps for each decade:
    1) Creation of weight maps from density of artificial surface (urbanisation). Density was defined as a combination of distance to nearest artificial surface, artificial surface in the direct neighbourhood, and artificial surface within a radius of 5km, 50km, and 150km. A 1% random component was included in order to ensure that no cells have the same weight.
    2) Allocation of new populated cells based on SSP-specific parameters. New populated cells in each LAD can only be created in non-masked space (same masks as in urbanisation model), when relative weight increases and when populated cells of lower weight exist. The number of new populated cells in each LAD is moderated by an SSP specific exogenous sprawl parameter and by the density of already populated cells, in order to curb undesired sprawl in low-populated LADs. This ensured consistency with narratives and semiquantitative trends.
    3) Allocation of population on each populated cell based on initial population, on weight change, and on population change at LAD level. The results are then rescaled linearly so that totals in each LAD match with LAD level projections.

Gross Domestic Product

- Linear interpolation was used between 2019 ONS historical data (Gross Domestic Product (GDP) - Office for National Statistics (ons.gov.uk)) and 2030 IIASA GDP estimates (SSP Database (iiasa.ac.at)), to produce projections between 2019 and 2030 for SSP1, SSP2, SSP4 and SSP5, and between 2019 and 2060 for SSP3.

- Projections are in line with the IIASA GDP estimates for the UK from the year 2030 for scenarios SSP1, SSP2, SSP4 and SSP5, and from the year 2060 for SSP3.

Gross Value Added

- The baseline is based on the ONS estimates from 2018 (Regional gross value added (balanced) by industry: local authorities by NUTS1 region - Office for National Statistics (ons.gov.uk)), available at the UK and Local Authority District level.
- To produce GVA projections between 2020 and 2100 at the UK level, the following steps were carried out:
  1) From historical data, calculate the ratio between GDP and GVA at the UK level, holding it constant in future years;
  2) Assume the sectoral breakdown of UK GVA to remain unchanged from the last year of data;
  3) Calculate GVA at Local Authority District level by growing historical data in line with working age population (taken from population projections);
  4) Scale Local Authority District estimates to the UK projections;
  5) Calculate local authority sectoral breakdown by assuming that sectoral breakdown (i.e., shares) are unchanged from last year of history;
  6) Carry out a two-dimensional scale (known as a RAS) to scale the local authority GVA by sector estimates to the local authority total GVA and the UK-level sectoral data.
- Consistency checks against UK-SSP narratives were carried out and a set of parameters for regional adjustment (convergence, divergence, and rural/urban adjustments) was identified. Regional adjustments were then implemented in order to match the projections with narratives.

Employment

- The baseline is based on the BRES estimates from 2019 (Nomis - Official Labour Market Statistics (nomisweb.co.uk)), available at the Local Authority District level.
- First, employment projections at the UK level were determined for SSP2 using OBR baseline employment projections (Fiscal sustainability report - July 2018 - Office for Budget Responsibility (obr.uk)) and assuming that the sectoral breakdown of UK employment is unchanged from the last year of data.
- For the other SSPs the following steps were carried out: 1) Calculate yearly productivity as ratio between the GVA projection in SSP2 and the employment projection in SSP2; 2) Assume productivity to remain the same across scenarios (over the period 2020 to 2100); 3) Apply the ratio to GVA projections to estimate employment projections at the UK level for SSP1, SSP3, SSP4 and SSP5.
- To estimate total employment projections between 2020 and 2100 at the Local Authority District level, the following steps were carried out: 1) Took historical total employment data at the Local Authority District level from BRES, year 2019, and projected forward in line with working age

population (taken from the population projections); 2) Scaled the local authority projections to the employment totals at the UK level in each projected year.

- To estimate employment projections between 2020 and 2100 by sector at the Local Authority District level, the following steps were carried out:
  1) Took historical sectoral employment data at the Local Authority District level from BRES, year 2019, and projected forward in line with working age population (taken from the population projections);
  2) Estimated sectoral shares in each projected year;
  3) Estimated local authority sectoral breakdown by multiplying the shares to the totals at the Local Authority District Level;
  4) Applied a RAS (two-dimensional) scale to ensure that the estimates match the local authority total employment and UK sectoral data series.
- Consistency checks against UK-SSP narratives were carried out and a set of parameters for regional adjustment (convergence, divergence, and rural/urban adjustments) was identified. Regional adjustments were then implemented in order to match the narratives.

Household Income

- The baseline is based on the ONS household income estimates from 2018 (Regional gross disposable household income: local authorities by NUTS1 region - Office for National Statistics (ons.gov.uk)), available at the Local Authority District level.
- To produce household income projections between 2020 and 2100 at the UK level, the following steps were carried out:
  1) From historical data, calculate the ratio between household income and GVA at the Local Authority District level, holding it constant in future years;
  2) The ratio is then applied to GVA projections, to obtain total household income projections at the Local Authority District level.

Projections based on trends from the E3ME-FTT model

- E3ME-FTT is a macro-econometric simulation model based on post-Keynesian economic theory, which allows for imperfect price adjustment, market disequilibrium and limited rationality of economic actors. It was developed over the last 25 years and it is one of the most advanced models of its type.
- The main E3ME-FTT scenarios (low, medium and high carbon) (see e3me.com) were originally developed for the FRANTIC project (Financial Risk and The Impact of Climate Change) which was granted from the UK's Climate Resilience program of the Natural Environment Research Council. However, these scenarios were not created with the same GDP assumptions of IIASA SSPs, therefore, results taken from the E3ME-FTT model scenarios for emissions, energy and electricity indicators are adjusted with IIASA GDP projections (see SSP Database (iiasa.ac.at)) to create five different SSPs based upon the IISA GDP projections.

- E3ME-FTT scenarios were initially created for the period of 2020-2070. Therefore, to cover the period of SSP narratives, the results were extended by 2100 with an extrapolation forecast method.
- These scenarios build upon historical data from the International Energy Agency.
- All results are presented at decadal intervals.

Emissions

- Emissions are quantified based on E3ME-FTT low, medium and high carbon scenarios and IIASA projections for GDP to obtain 5 SSP scenarios.
  - Emissions data from the E3ME-FTT scenarios are divided by GDP results from the same scenario to calculate emissions intensity of output
  - The low (SSP1 and SSP4), medium (SSP2) and high (SSP3 and SSP5) intensities are matched to SSP-specific GDP trajectories from IIASA and multiplied together to calculate total emissions.
- CO2 emissions do not include those from land-use.

Energy

- For energy use, total primary energy supply is quantified.
- The primary energy supply projections which were developed with E3ME-FTT model are adjusted in the same way as emissions (i.e., based on intensities) to be consistent with the IIASA GDP projections for each SSP.

Electricity

- Electricity generation is projected, first at the aggregate level using E3ME-FTT scenarios, adjusted based on electricity-intensity of output to be consistent with the IIASA GDP projections for the SSPs.
- The total is disaggregated by technology type (onshore wind, offshore wind, solar PV, hydro, coal, gas, etc.), based upon the shares in the E3ME-FTT scenarios, but also subject to some adjustment to ensure consistency with the UK-SSP narratives for each scenario.

Technological Development

- The technological development indicators are developed based on the high, medium and low carbon scenarios created for the FRANTIC project in the E3ME-FTT model (there’s no equivalent data from the IAMs for us to scale to across the five SSPs, and therefore it’s not possible to directly amend the three scenario trajectories to make them consistent).
- In order to quantify this indicator, cost component and cumulative capacity of each technology are considered. Technological development indicators show how the investment cost of low or high carbon technologies are changing due to cumulative installed/adopted capacity (and associated learning effects) over time.
- The E3ME-FTT macroeconomic model has four main sub-models to represent Future Technology Transformations (FTTs) in specific sectors. Therefore, technological development indicators are quantified for the following sectors separately: Power, Transport, Heating, and Steel. The results are presented by using aggregated data on cumulative cost reductions for high or low carbon technologies in each sector. For instance, for technological development indicators in the power sector,

high carbon is represented by the cost evolution of fossil-based technologies, while low carbon includes the evolution of renewable energy technologies.

Projections based on PLUM/LandSyMM model

PLUM simulates global demand and trade of agricultural commodities (e.g., cereals, oil crops, pulses, starchy roots, sugar, fruits and vegetables, wood, dairy and meat products from ruminant livestock and monogastric livestock) based on least-cost optimisation within in each country. The yield potentials are used to select irrigation, fertilizer use and management intensity (e.g., pesticide and machinery use) with a 0.5° grid spatial representation. International trades decisions account for trade tariffs and transport costs.

Food demand & trade

- SSP-specific projections of food demand in food commodity groups were created from empirical relationships to GDP (Rabin et al., 2020) and considering changes in international trade.
- Disaggregation of demand, use and trade into to individual foods items was done using FAO Commodity Balance Data. Demand was adjusted to apply stakeholder assessments of shift between animal products and plant-based foods, as well as reduction in food losses, for each SSP.

Projections from the CRAFTY model

- CRAFTY-UK is a spatially-explicit (1 km grid) agent-based model of land use change (for agricultural, forestry and nature conservation uses), including the intensity of land management. The UK-SSPs determine the levels of the socio-economic capitals (human, social, financial and manufactured) that are the attributes of place that agents use in their production strategies.
- The release in May 2021 is a beta version of the model.
- Natural capitals (production productivities for crops, grass and tree growth) were derived using a combination of statistical and process-based modelling approaches in response to the RCP climate change scenarios (for RCP4.5 and RCP8.5 derived from the HADGEM3 ESM).
- CRAFTY-UK simulates the competition for these capital resources, but also agent cooperation through social networks, which facilitates the exchange of knowledge.
- Agents supply multiple ecosystem services (e.g., food, timber, carbon stocks, biodiversity, recreation) in response to the demand for these services.
- Demand levels for ecosystem services were inferred for the UK-SSPs or modelled as in the case of food and feed (see below).

Food Production

- Food production was simulated using the CRAFTY-UK agent-based model for food crops, feed crops and livestock products (ruminant and monogastric meat and milk).
- Food demand, as well as the import and export of food and feed commodities were derived from the LandSyMM global land system model, including global trade for the global SSPs.

Land Use

- Land use was derived from the CRAFTY-UK model.

Land Use Intensity

- We use land-use intensity as a proxy variable for agricultural inputs (fertiliser use, pesticides, etc.).

- CRAFTY-UK simulates land use intensity, e.g., conventional vs organic arable crops, intensive, extensive and very extensive grassland systems.
- For intensity, land use classes ranked in the following order:
  - urban,
  - intensive agriculture food, intensive agriculture fodder,
  - intensive pastoral,
  - agroforestry,
  - bioenergy,
  - productive NN broadleaf, productive NN conifer,
  - productive N broadleaf, productive N conifer,
  - extensive pastoral, extensive agriculture, sustainable agriculture,
  - mixed woodland,
  - very extensive pastoral
  - natural woodland conservation
  - unmanaged.

Projections based on trends derived from UK-SSP narratives

Where other models were not available, projections were calculated with central trends and regional adjustments in a process of seven steps:

1) Analysis of the distribution of historical data in the UK, and comparison to European and worldwide data, where available.
2) Definition of projection boundaries and thresholds for five categorical bands from “very low” to “very high”, based on the analysis in step 1 and expert judgement.
3) Definition of central trends for each scenario, using a Delphi approach in an expert panel that draws upon the semi-quantitative trends and scenario narratives.
4) Creation of projections based on these trends and mapping of results.
5) Review of maps, consistency checks against UK-SSP narratives, and definition of regional adjustment parameters for convergence, divergence, and rural/urban adjustments in order to match the narratives.
6) Implementation of regional adjustments and mapping of results.
7) Review of maps and final checks for consistency with narratives and other projected variables.

Health

- We used life expectancy at birth as an indicator for health. The baseline is ONS life expectancy data from 2018, available at Local Authority District level: https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthandlifeexpectancies/datasets/lifeexpectancyatbirthandatage65bylocalareasuk

Healthcare

- Headcount number of GPs (excluding registrars and locums) per 100 000 capita was used as an indicator for healthcare. The baseline was constructed with national workforce datasets from the four UK nations and aggregated to NUTS 2 level:
  - England general practice workforce data from 2020 available at Clinical Commissioning Group level (General Practice Workforce 30 September 2020 – NHS Digital (digital.nhs.uk))

- Wales general practice workforce data from 2020 available at postcode level (General practice workforce: as at 30 June 2020 – Welsh Government (gov.wales))
- Scotland general practice workforce data from 2019 available at local authority district level (General practice - GP workforce and practice list sizes 2009 - 2019 – Public Health Scotland (isdscotland.org))
- Northern Ireland general medical service data from 2020 (General Medical Services Statistics – HSC Business Services Organisation (hscbusiness.hscni.net)).

Inequality

- Regional income quintile ratios were used as an indicator for inequality. The baseline is OECD income inequality data from 2011, available at NUTS 1 level (Regional Well-Being: Regional income distribution and poverty – OECD.Stat (stats.oecd.org))
- This was downscaled to NUTS 3 in the quantification process, in order to be used as an input to the land use model.

Regional Development Transfers

- The difference between the England net fiscal balance per capita and the UK net fiscal balance per capita was used as an indicator for fiscal transfers from England to the rest of the UK. The baseline is ONS net fiscal balance data from 2017, available at NUTS 1 level as well as at UK four nations level.

Road Infrastructure

- Speed-weighted length of roads per area was used as an indicator for road infrastructure. The baseline is GRIP road infrastructure vector data from 2015 (GRIP global roads database – GLoBio (globio.info)).
- This indicator was calculated for local authority districts.

Rail Infrastructure

- Length of railway lines per area was used as an indicator for rail infrastructure. The baseline is WFP rail infrastructure vector data from 2008 (Global railways (WFP SDI-T - Logistics Database) - OCHA Services (data.humdata.org)).
- This indicator was calculated for local authority districts.

Regional Development Transfers

- Difference between the England net fiscal balance per capita and the UK net fiscal balance per capita was used as an indicator for fiscal transfers from England to the rest of the UK. The baseline is ONS net fiscal balance data from 2017, available at NUTS 1 level as well as at UK four nations level (Country and regional public sector finances: financial year ending 2017 – ONS (ons.gov.uk)).

R&D Expenses

- Intramural R&D expenses in all sectors per capita were used as an indicator for R&D. The baseline is Eurostat data from 2018, available at NUTS 2 level (Regional Statistics by NUTS classification – Eurostat (ec.europa.eu))
- The currency was converted to £ 2018.

Education

- The share of population in the age band of 25 – 64 with tertiary education was used as an indicator for education. The baseline is Eurostat data from 2019, available at NUTS 2 level (Population by educational attainment level, sex and NUTS 2 regions (%) - Eurostat (ec.europa.eu))

- This was downscaled to LAD in the quantification process, in order to be used as an input to the land use model.

Social Cohesion

- The share of population agreeing to the statement “people around here are willing to help their neighbours” was used as an indicator for social cohesion. The baseline is UK Household Longitudinal Survey data from 2015 (wave 6) with 30602 usable observations, available at local authority district level but aggregated to NUTS 3 level due to low observation numbers in some areas (Understanding Society: Waves 1-10, 2009-2019 and Harmonised BHPS: Waves 1-18, 1991-2009 – UK Data Service (beta.ukdataservice.ac.uk)).

Values & Attitudes re. Environment

- The share of population describing their lifestyle as environmentally friendly was used as an indicator for values & attitudes regarding the environment. The baseline is UK Household Longitudinal Survey data from 2013 (wave 4) with 38769 usable observations, available at local authority district level but aggregated to NUTS 3 level due to low observation numbers in some areas (Understanding Society: Waves 1-10, 2009-2019 and Harmonised BHPS: Waves 1-18, 1991-2009 – UK Data Service (beta.ukdataservice.ac.uk)).

Produced Capital

- Gross fixed capita formation per area was used as an indicator for produced capital. The baseline is Eurostat data from 2017, available at NUTS 2 level (Regional Statistics by NUTS classification – Eurostat (ec.europa.eu)). Values in each NUTS 2 area were divided by the respective area sizes.
- This was downscaled to LAD level in the quantification process, in order to be used as an input to the land use model
- The currency was changed to £ 2018.

Capital Availability (Savings)

- The share of population saying that they “save any amount” of their income was used as an indicator for savings and capital availability. The baseline is UK Household Longitudinal Survey data from 2017 (wave 8) with 37036 usable observations, available at local authority district level but aggregated to NUTS 3 level due to low observation numbers in some areas (Understanding Society: Waves 1-10, 2009-2019 and Harmonised BHPS: Waves 1-18, 1991-2009 – UK Data Service (beta.ukdataservice.ac.uk)).

5 Quality assurance

5.1 Quality assurance checks for the scenario narratives, system diagrams and semi-quantitative trends

Quality assurance checks on the scenario narratives and system diagrams were undertaken as part of the participatory process and by the project team.

The enriching and expanding of the UK-SSP scenario narratives was carried out over three sessions in the online workshop (see Chapter 2). First, breakout groups were created for each UK-SSP and in each group, the main scenario features were reiterated. The participants were invited to live review a shared Google document containing the original narrative from the UK-SCAPE project and include comments on gaps and inconsistencies. These were subsequently discussed, and the deliberated changes were implemented live by the facilitator into the text of the narrative. After a session on creating system diagrams and a virtual tour of the extended UK-SSPs, the same method of live editing was repeated to incorporate insights from the building of the system diagram and feedback from other groups, as well as to further check, refine and expand the nation-specific parts of the storylines.

The breakout session focused on participatory co-design of system diagrams was placed between two sessions focusing on the scenario narratives, so that (1) the first session on narratives identified the missing interrelationships, (2) the session on system diagrams allowed the participants to visualise system considerations in detail and clarify the interrelationships explicitly, and (3) the second session on narratives enabled the newly acquired understanding of the interrelationships to be incorporated into the narratives. This allowed a more explicit check for internal inconsistencies in the UK-SSPs and clarified which aspects of the narratives needed to be further enriched.

The final two breakout sessions focused on the participatory development of semi-quantitative trends for specific variables for the UK-SSPs and deliberating a consensus version of the trends. These sessions used the detailed knowledge of the scenario narratives and system diagrams to create and deliberate trends. The short explanation/rationale for each trend was also used by the project team to cross-check and/or enrich the narratives.

The online workshop produced a vast amount of input from the participants. This information was subsequently cleaned and processed by the research team. This process included several quality assurance checks:

- the 14 key socio-economic driver categories were covered throughout all five scenario narratives, the extent to which was allowed to vary depending on the importance of the role of each driver category in the UK-SSP;
- the five UK-SSP narratives were consistent in terms of both content and presentation;
- the UK-SSP narratives were accurately represented in the system diagrams, and the interrelationships shown in the system diagrams were described within the narratives;
- The semi-quantitative trends from the different sources were consistent with the narratives and each other.

During the data processing, gaps were identified 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 to fill in remaining gaps and validate the resulting UK-SSPs.

For the final questionnaire survey, the near final versions of the narratives were sent to the stakeholders who participated in the workshop sessions and semi-structured interviews on the narratives to ensure that we had correctly interpreted and elaborated their local and expert knowledge. The questionnaire asked the participants whether the narrative reflects the discussions during the workshop (on a scale between 1 for not at all and 5 for fully). The majority of respondents (68% response rate) 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).

5.2 Quality assurance carried out on quantified socioeconomic indicators

This section outlines the quality assurance checks carried out when producing the quantified projections of key socioeconomic indicators.

Quality control challenges	Solutions (How a check has been carried out)
Consistency of quantitative variables with qualitative storylines	Verification across the project team of the consistency between the qualitative and quantitative data
Anomalies in the data (negative values, very high or very low values)	Automated checks (e.g. conditional formatting, min, max, range calculations), charting data
Drastic or unexpected changes in growth rates that change the course of the projection.	Check explicitly for smooth trajectories in the projections. Charting data, automated checks on growth rates.
Plausibility	Ensure results are realistic/plausible within the timeframe, and that they make sense within our scenario narratives. Spot checks on data points at specific time intervals, e.g., 2030, 2050, 2100, charting data. Average growth rates over the projection period were calculated at a national level and spot checked at regional and local authority level. The plausibility of these growth rates was evaluated. Shares of UK total for each region/local authority in start year and end year were used to check whether results seem plausible.
Consistency of disaggregated projections with aggregate trends	Ensure disaggregated data shares sum to 100%, where required.

	Automated checks, e.g., compare sum of LAs to regions, sectors to totals.
Consistency between socioeconomic indicators	Ensure projections of related indicators move in the same direction/ follow similar patterns. Chart data, random spot checks, calculation and checking of implied intermediate data. Ratios that were calculated and checked include: • GDP per capita • R&D expenditure per capita • GDP / GVA • GVA per capita • Ratio between population and land used for 'settlement' • Total energy generation per capita • Employment to population ratio (number of people employed/ working age population) • R&D expenditure intensity (R&D/ GDP) • Energy intensity (total energy demand/ GDP) • Total residential energy demand per household
Plausibility within the international context	Sense checks of projection boundaries against European and worldwide data. For all variables quantified with narrative-derived central projection trends, the maximum and minimum boundaries of the projections were derived from historical data in the UK, Europe and the world, where such data was available.
Inconsistent spatial boundaries from ONS	Consistency checks in all steps of historical data aggregation and disaggregation.
Misallocations of urban cells	Automated pixel allocation checks in the urbanisation model. Projection algorithm includes automated checks and corrections of pixel allocations.
Data structure	Workbook is designed to give maximum usability, including contents page and metadata.

6 Using the UK-SSP products

6.1 How various UK-SSPs products can be used together

Throughout the project there was ongoing iteration between the development of the UK-SSP narratives, systems diagrams and semi-quantitative trends, and the quantification of projections. Quantified projections were drafted, then checked against the scenario narratives and other qualitative products. Where differences were identified, decisions were made about consistency with the over-arching narrative and either the projections or the qualitative products were amended accordingly. This iterative process means that there is a robust relationship between the qualitative and the quantitative data products, with each product informing the other.

The products are therefore designed to be used in harmony together, with the narratives and other qualitative products describing the socioeconomic conditions of the future, the storyline behind the development of these conditions and the detailed interrelationships between key socioeconomic drivers. These products provide the user with a deep understanding and descriptive background to the future socioeconomic circumstances explored through each UK-SSP. Meanwhile, the quantified projections provide robust data to accompany these storylines, to be used in quantitative modelling and analyses.

6.2 Examples of analysis UK-SSP products could be used for

Scenario narratives

- Qualitative analysis of the existing narrative content (e.g., to assess factors related to climate risks, adaptive capacity, barriers/enablers to actions, etc)
- Use to stress-test the robustness of climate (or other policies) under the different futures
- Use as the basis for co-creating adaptation/mitigation/transformation pathways to desirable futures or policy goals (e.g., net zero)
- Use as the basis for further extensions:
  a) For specific regions, e.g., LADs, cities
  b) For specific sectors, e.g., health, water
  c) For specific time periods, e.g., next 10 or 30 years, or climate or societal extremes/shocks
- Build on the systems diagrams, e.g., further elaboration, participatory systems modelling
- Use as the basis for semi-quantifications/quantification of variables not already covered.

Semi-quantitative trends

- For quick orientation in the scenario assumptions
- To use as an input for further quantification, modelling and downscaling
- With the system diagrams, to guide the identification of cross-driver and cross-sectoral links.

Quantified projections

- Providing quantitative input parameters for climate change impacts and adaptation modelling and assessment
- Quantitative analyses of climate risks and vulnerabilities by representing exposure and adaptive capacity to climate hazards
- Evaluating the range of plausible, quantitative outcomes for a range of socio-economic indicators
- Supporting an analysis of the regional differences in multiple socio-economic indicators across the UK.

6.3 Further research needs

- Further research to identify methods for combining UK-SSPs with UKCP18, to develop a comprehensive framework similar to the global SSP-RCP framework.
- Further stakeholder engagement to refine the storylines in light of the resulting quantitative socio-economic indicators.
- Development of Shared Policy Assumptions (SPAs) for the UK related to its net zero target to combine with the UK-SSPs and UKCP18.
- Evaluation of how policy interventions and societal change might direct the UK towards more desirable future outcomes across policy areas (e.g., the climate, biodiversity and inequality crises).
- Definition of future visions (goals and targets) for the UK, and stress-testing of pathways to achieve these visions within the constraints of the UK-SSPs.
- Further refinement of the CRAFTY-UK land use change model to include new parameterisations for the storylines and to include additional processes not already modelled. An example is better representation of natural capital (land use suitability) as an input parameter.
- Development of semi-quantitative trends and spatial projections for a wider range of socio-economic variables.
- Further downscaling of key socio-economic variables, e.g., population.