



Future Changes in Indicators of Climate Hazard and Resource in the UK

Nigel Arnell, Stephen Dorling, Hayley Fowler, Helen Hanlon, Katie Jenkins and Alan Kennedy-Asser

Abstract

- The UK Climate Resilience Programme (UKCR) funded several projects that have calculated how climate change is likely to affect climate hazards and resources across the UK, using the latest UK Climate Projections (UKCP18).
- Under a high emissions scenario, heatwaves and high temperature extremes become more frequent across the UK, leading to an

Lead Author: Nigel Arnell

Contributing Authors: Stephen Dorling, Hayley J. Fowler, Helen Hanlon, Katie Jenkins, Alan L. Kennedy-Asser

N. Arnell (✉)
University of Reading, Reading, UK
e-mail: n.w.arnell@reading.ac.uk

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increase in human mortality, animal heat stress, potato blight, wild-fire danger and damage to road and rail infrastructure. Cold weather extremes continue to occur but become less frequent.

- Also under high emissions, the growing season starts earlier, lasts longer and is warmer; this is particularly beneficial for grassland and viticulture, but the chance of summer drought and dry soils increases. The precise effects vary across different agricultural systems.
- With respect to rainfall, high hourly and daily totals become more frequent, leading to a greater chance of flash flooding. River floods become more frequent in the north and west of the UK, but low river flows and droughts also become more frequent, and water quality in upland water sources declines. The actual size of the change in risk is uncertain, primarily due to uncertainty in exactly how rainfall will change.
- There are large differences in change in risk across the UK. However, the actual size of the change in risk is uncertain, primarily due to uncertainty in exactly how rainfall will change.

Keywords Climate risk · Climate hazards · Climate resources · UKCP18

1 INTRODUCTION

Over the last 30 years, several studies have sought to quantify the potential impacts of climate change in the UK in order to understand how risks might change and to inform adaptation and resilience policy in

S. Dorling · K. Jenkins
University of East Anglia, Norwich, UK

H. Fowler
Newcastle University, Newcastle Upon Tyne, UK

H. Hanlon
Met Office, Exeter, UK

A. Kennedy-Asser
University of Bristol, Bristol, UK

specific areas. Since 1998, a series of national climate projections have been produced, with the most recent UK Climate Projections published in 2018 (UKCP18) [1]. The UK Climate Resilience Programme (UKCR) funded a series of projects that characterised future climate risks and opportunities across UK sectors under its ‘Climate Risks’ theme. This chapter draws together published results from these projects. It focuses on indicators of change in climate hazard and resource and concentrates on how these indicators change in a world with continued high emissions. The indicators characterise change in vulnerability and risk, and therefore, help inform the development of policy and decision-making on adaptation and resilience.

The paper is organised into three sections, outlining the potential changes in hazard and resource that have been calculated during the UKCR programme, summarising how the results are being used and identifying important remaining gaps.

2 CHANGES IN HAZARD AND RESOURCE ACROSS THE UK

The weather and climate at a place constitute both a hazard (something that has the potential to cause harm, such as drought and flooding) and a resource (something that enables or constrains an activity, such as renewable energy generation). Heatwaves, floods and droughts are the most obvious hazards, while agriculture and building heating requirements are strongly influenced by climate resources. A change in climate alters these hazards and resources and will impact many areas, including health, infrastructure and the natural environment. Future impacts will depend on how the economy and society changes over time—and what measures are put in place to adapt and increase resilience—so are sensitive to assumptions about both trends and decisions. Another way of looking at the effects of climate change is to examine how indicators that relate to decisions and actions might change: how often, for example, would the thresholds that trigger emergency plans, or that are known to cause operational challenges, be crossed? Such information helps inform the development of adaptation and resilience policy.

Several UKCR projects took this approach; the results are summarised here, grouped into three sectors as classified in the Technical Report for the Third Climate Change Risk Assessment (CCRA3) [2]: (1) natural environment and assets; (2) infrastructure; and (3) health, communities

and the built environment. Table 1 presents a high-level overview of changes in hazard and resource, together with some example quantifications for the 2050s, while the following sections provide more detail. It is important to emphasise that the indicators presented do not necessarily characterise the full range of climate risks in the UK, and that the summary concentrates on research undertaken by UKCR projects specifically.

The indicators referred to in this chapter are listed in Table 1, alongside the corresponding UKCR projects. These studies used the latest UKCP18 climate projections [1], so the following section outlines these projections and details how they have been used.

2.1 Climate Projections and the Construction of Climate Scenarios

The UKCP18 land climate projections consist of four strands [1, 15], three of which (global, regional and local) describe changes in climate with the very high emissions ‘RCP8.5’ scenario, where global average temperature increases well above 4°C by the end of the twenty-first century. The three strands are based on climate models at different spatial resolutions, so provide information at different scales. The finer resolution models typically provide better information on short-duration, localised weather processes. All are based on variants of the Met Office HadGEM3.05 climate model, and therefore represent only a portion of the range of possible modelled future climates. The global strand combines the HadGEM3.05 model with other climate models, so gives a broader range of possible outcomes.

The fourth strand—the probabilistic projections—not only includes many more climate models, but also includes projections for a wider range of assumptions about future emissions. The projections are intended to characterise the most complete range of uncertainty in how climate is likely to change in the UK in future. In practice, most of the studies of the UKCR programme have used the regional and local strand HadGEM RCP8.5 projections because they are spatially and temporally coherent; very few have used the probabilistic projections. Different studies have used slightly different time periods to define the current reference period and have used a variety of approaches (bias-adjustment or delta methods) to create climate scenarios.

Table 1 Changes in indicators of climate hazard and resource by the 2050s, based on the central estimate from the HadGEM UKCP18 strand (global, regional or local), with very high RCP8.5 emissions

<i>Indicator</i>	<i>Projected change</i>	<i>UKCR project</i>
Natural environment and assets		
The crop growing season starts earlier and lasts longer	<ul style="list-style-type: none"> growing season starts around 30 days earlier and ends around 15 days later 	Climate Risk Indicators Ref: uk-cri.org
Growing degree days increase	<ul style="list-style-type: none"> growing degree days increase by over 50%, with slightly greater increases in the north 	Climate Risk Indicators Ref: uk-cri.org
Frost days decrease	<ul style="list-style-type: none"> frost days decrease by around 60% 	Climate Risk Indicators Ref: uk-cri.org
Growing seasons for viticulture become warmer and longer	<ul style="list-style-type: none"> growing season temperatures increase by around 1.5°C and growing degree days increase by 25% (by 2021–2040) early season air frosts occur on around five fewer days per year high inter-annual variability remains a consistent feature 	CREWS-UK Ref: Nesbit et al. [3]
Soil moisture deficits increase in summer	<ul style="list-style-type: none"> average potential soil moisture deficit increases by 75% in England and over 50% in Scotland 	Climate Risk Indicators Ref: uk-cri.org
Agricultural drought risk increases	<ul style="list-style-type: none"> average proportion of time <i>in rainfall</i> drought nearly doubles in England, and when evaporation is included increases by a factor of four increases are lower in Scotland and Wales 	Climate Risk Indicators Ref: uk-cri.org
Warm and dry summers become more common	<ul style="list-style-type: none"> average chance of getting two warm and dry months increases from 10 to 40% 	Multiple Hazards Ref: Garry et al. [4]

(continued)

Table 1 (continued)

<i>Indicator</i>	<i>Projected change</i>	<i>UKCR project</i>
Potato blight becomes more frequent	<ul style="list-style-type: none"> number of days with blight risk increases by 24% in eastern England and 67% in eastern Scotland (the two main potato growing regions) 	Multiple Hazards Ref: Garry et al. [4]
Thermal heat stress to dairy cattle increases	<ul style="list-style-type: none"> number of days with stressful conditions increases by a factor of 24 in southwest England 	Climate Risk Indicators Ref: uk-cri.org
Wildfire danger increases across the UK	<ul style="list-style-type: none"> chance of days with 'very high' wildfire danger more than doubles across England, Wales and Northern Ireland, with slightly lower increases in Scotland 	Climate Risk Indicators Ref: Arnell et al. [5] and Perry et al. [6]
Infrastructure		
Road accident risk due to ice decreases	<ul style="list-style-type: none"> average number of days across UK with risk of icing falls by 70% 	Climate Risk Indicators Ref: Arnell et al. [7]
High temperature extremes affecting rail infrastructure increase	<ul style="list-style-type: none"> average number of days in England with maximum temperatures greater than 26°C increases by factor of five, and by a greater amount in Scotland and Wales 	Climate Risk Indicators Ref: Arnell et al. [7]
Adverse rail operating days increase in England, but decrease in Scotland	<ul style="list-style-type: none"> adverse days nearly double in England adverse days decrease by 25% in Scotland but increase after 2050 	Climate Risk Indicators Ref: Arnell et al. [7]

(continued)

Table 1 (continued)

<i>Indicator</i>	<i>Projected change</i>	<i>UKCR project</i>
Short-duration rainfalls become more frequent	<ul style="list-style-type: none"> • average number of days with high rainfall in England and Wales doubles • in the north and west the 30-year return period is over 30% larger than at present, with smaller increases in the south and east 	FUTURE-DRAINAGE Ref: Chan et al. [8] Multiple Hazards Ref: Hanlon et al. [9]
River flows decrease in summer and (in the north and west) increase in winter	<ul style="list-style-type: none"> • average winter runoff in Wales increases by 11% • average summer runoff falls by over 40% in England and Wales 	Climate Risk Indicators Ref: Arnell et al. [7]
River floods become larger and more frequent in the north and west	<ul style="list-style-type: none"> • the 10-year flood is at least 10% larger in the north and west • the current 10-year flood occurs up to twice as often in the north and west 	Climate Risk Indicators Ref: Kay et al. [10]
Low river flows decrease and become more frequent across the UK	<ul style="list-style-type: none"> • the 10-year return period low river flow is halved across England and Wales, and reduced by a third in Scotland • the current 10-year return period low flow occurs four times as often in England and Wales, and twice as often in Scotland 	Climate Risk Indicators Ref: Kay et al. [10]
River drought frequency increases across the UK	<ul style="list-style-type: none"> • the amount of time in severe hydrological drought doubles across Britain 	Climate Risk Indicators Ref: Arnell et al. [7]
Dissolved organic matter increases in upland drinking water sources	<ul style="list-style-type: none"> • dissolved organic matter concentrations increase by over 30% in autumn in example upland catchments 	FREEDOM-BCCR Ref: Monteith et al. [11]

(continued)

Table 1 (continued)

<i>Indicator</i>	<i>Projected change</i>	<i>UKCR project</i>
Health, communities and the built environment		
Heatwaves and heat-health alerts become much more frequent, particularly in the south and east	<ul style="list-style-type: none"> • average chance of a Met Office defined heatwave increases from 42 to 96% in England • average chance of a heat-health alert increases from 7 to 63% 	Climate Risk Indicators Ref: Arnell and Freeman [12]
High temperature extremes become much more frequent, particularly in the south and east	<ul style="list-style-type: none"> • average number of days per year with maximum temperatures greater than 25°C increases from eight to 25 across the UK • average number of tropical nights per year (minimum temperatures greater than 20°C) increases from less than 0.02 to almost three in England • average number of days per year with heat stress (wet-bulb globe temperature in shade > 25°C) increases from 0.1 to over four in England 	Climate Risk Indicators Ref: Arnell and Freeman [12] uk-cri.org OpenCLIM Ref: Kennedy-Asser et al. [13]
Heat-related mortality increases	<ul style="list-style-type: none"> • heat-related mortality in summer increases by over 30% 	Health Sector Resilience Ref: Huang et al. [14]
Cold weather extremes reduce but remain common	<ul style="list-style-type: none"> • average chance of a cold weather alert decreases from almost 100% to 56% in England 	Climate Risk Indicators Ref: Arnell and Freeman [12]
Cold-related mortality decreases	<ul style="list-style-type: none"> • cold-related mortality in winter decreases by 18% 	Health Sector Resilience Ref: Huang et al. [14]

(continued)

Table 1 (continued)

<i>Indicator</i>	<i>Projected change</i>	<i>UKCR project</i>
Heating degree days reduce	<ul style="list-style-type: none"> heating degree days decrease by 30% in England and 48% in Scotland 	Climate Risk Indicators Ref: Arnell et al. [7] Multiple Hazards
Cooling degree days increase	<ul style="list-style-type: none"> cooling degree days increase by a factor of four in England and five in Scotland 	Climate Risk Indicators Ref: Arnell et al. [7] Multiple Hazards Ref: Hanlon et al. [9]

2.2 *Natural Environment and Assets*

While this sector encompasses natural environments, agriculture, forestry and the landscape [16], studies published thus far have concentrated on wildfire (the hazard) and on indicators relevant to agriculture.

Wildfires in the UK are typically a result of human action (usually inadvertent), but the fire danger at a place depends on current and preceding weather. Projected higher temperatures, lower humidity and increased drought conditions result in increased wildfire danger across the UK, particularly in the south and east [5, 6]. Each indicator presents a different degree of change with respect to wildfire danger, but all point to an increase in risk.

Regarding UK agriculture, projected warmer temperatures increase the duration of the growing season, which serves to both increase growing degree days and reduce early season frost frequency—conditions that benefit grass and potentially other crops such as vines [3, 4, 9, 17]. However, summer soil moisture deficits increase across the UK (particularly in the south and east) due to drier summers and greater evaporation. This potentially limits production of crops without supplementary irrigation. Agricultural drought risk increases with increasing temperature across the UK, with a large uncertainty range primarily due to uncertainty in projected changes in rainfall [9, 17]. With very high RCP8.5 emissions, the chance of having two warm and dry summer months in a year—which is challenging to agriculture—would increase from less than 10% now to over 40% by the 2050s, but again with a large uncertainty range [4].

Projected high temperatures, coupled with high humidity, also lead to increased risk of potato blight (particularly in typically cool areas)

[4], lower milk yields from dairy cattle owing to increased heat stress (particularly in the south and east) [4, 17] and a substantial increase in the occurrence of debilitating sheep parasites (in the south and west) [17]. The annual number of days with very wet soils, which limits access to land, decreases in future [17]. This reduction occurs mainly during autumn, which would potentially help with the drilling of winter crops and establishment of robust rooting systems.

Taken together, these changes in climate imply some opportunities for UK agriculture (especially at lower emission scenarios), but also mean increasingly challenging conditions associated with extreme events for many types of farming. The precise impacts on yields will vary between crop type and variety, depending on their resilience to changes in temperature, rainfall and associated pests and diseases.

2.3 *Infrastructure*

This sector covers the UK infrastructure providing services such as heating, lighting, mobility, freshwater and sanitation to society and protecting against extreme events [18].

The number of days with ‘heavy’ rainfall above thresholds used in the Met Office National Severe Weather Warning Service is projected to increase into the future [9], implying more frequent flash flooding. The magnitude of rainfall events with a specific chance of occurring—such as one in 30 years—is projected to increase [8, 19]. The increases are proportionally greater in the north and west.

Changes in hourly and daily extreme rainfall such as these would directly affect flash flood risk (e.g. in urban areas), but not necessarily directly affect river flood risk. Small and impermeable catchments respond rapidly to short-duration rainfall, while flooding in larger catchments or catchments with more storage reflects longer-term accumulations of rainfall over days or weeks. The general picture is for an increase in flood risk (interpreted as change in either magnitude or frequency) across northern and western parts of the UK, resulting from increased rainfall and potentially slower-moving rainstorms [20]. In the south and east, there is more of a mixed picture [10, 21], with considerable uncertainty in the amount of change. The projected increase in flooding increases the erosion risk to bridges and other infrastructure [22].

At the same time, reductions in spring, summer and autumn rainfall across southern and eastern England result in lower summer and autumn

river flows [10, 21], increased frequencies of hydrological drought [23] and associated pressure on water resources and the water environment—although the uncertainty range is again large.

High temperature extremes affect the performance and maintenance of road and rail infrastructure (e.g. causing road surfaces to melt and track/signalling equipment to malfunction), while low temperatures increase road accident risk through road icing [23]. High temperature extremes are projected to become much more frequent, reducing the reliability of road and rail infrastructure and increasing the frequency of failure. Low temperature extremes become less frequent but will continue to occur.

Adverse weather conditions can also affect operations on the railways. Characterised as hot, cold, wet and windy extremes, occurrences of ‘adverse weather’ impacts punctuality standards. Across England and Wales, the number of days with adverse weather is projected to increase with warming [23], primarily because hot days increasingly dominate. In contrast, adverse conditions in Scotland are strongly influenced by cold weather, and these decrease over time.

The reliability of renewable energy supplies is potentially affected by changes in climate, but changing demand (see below) will be more important than the projected small variation in the frequency of ‘wind drought’ [24, 25].

2.4 *Health, Communities and the Built Environment*

This sector concentrates on risks to the UK population, focusing on health and wellbeing, as well as the built environment [26].

Extreme high temperatures in the UK are projected to increase more rapidly than global average temperatures [13, 27]; the number of days above specific temperature thresholds increases substantially, particularly in the south and east [9, 23]. Two definitions of heatwave are currently used operationally, one by the Met Office to declare a heatwave (primarily for communications purposes) and one used in England in the health and social care system. Under both definitions, the number of events is projected to increase significantly. When translated into risk of human mortality [14, 28], risks increase with temperature in a very non-linear way and accelerate as temperature rises. Extreme heat stress arises where high temperatures are associated with high humidity; high heat-stress days are currently very rare in the UK, but the chance of experiencing them in future increases very substantially in the south-east [12, 13]. At the

other extreme, cold weather events become less frequent [9, 12], but will still occur with sufficient frequency that they need to be considered for planning purposes.

Extreme windstorms are likely to increase in frequency throughout the twenty-first century, with a large proportion likely to feature very high windspeeds due to ‘sting jets’ [29] leading to an increased risk of property damage.

Heating degree days (a proxy for the demand for residential heating) decrease by about 18% and 35% at 2°C and 4°C warming, respectively [9, 23], with the percentage change relatively consistent across the UK. The uncertainty range is small because there is relatively little uncertainty in how UK average temperature changes with global average temperature. Cooling degree days (a proxy for overheating and therefore cooling requirements) increase from a low baseline, and therefore, percentage changes are potentially misleading. However, there is much more variability across the UK, with the greatest increase experienced in the south and east.

3 HOW HAVE THE RESULTS BEEN USED SO FAR?

A wide range of indicators of current and future climate hazard and resource across the UK are available from the Climate Risk Indicators website, an interactive tool enabling users to map indicators and plot time series at scales ranging from local authority area to the four nations of the UK. This resource has been used by several organisations to understand local and regional climate risks, and some (e.g. The Wildlife Trusts) [30] have combined the indicators with their own data to create customised risk maps. Results and figures also figure prominently in the CCRA3 Technical and Synthesis Reports. The UK Heat Stress Vulnerability website allows users to produce maps of current and future heat stress, combining metrics of heat hazard with metrics of vulnerability, which has been used by the Welsh Government [31]. The projected changes in short-duration rainfall produced in the UKCR project ‘FUTURE-DRAINAGE’ [18] have been used to define new peak rainfall climate change allowances for both England [32] and Scotland [33]. The UK Government’s CCRA3 [34] refers to both the climate risk indicators website and ‘FUTURE-DRAINAGE’. The results from several projects have also been used as the basis for more specific investigations for individual public and private sector organisations.

4 GAPS AND CHALLENGES

Taken together, the UKCR-funded studies of changing climate risk in the UK have demonstrated the potential for large, adverse impacts and increases in risk. Also highlighted, however, are the large uncertainty ranges, primarily due to uncertainty in how mean and extreme rainfall across the UK will change over time. The studies have used slightly different approaches in detail, but all produce comparable results. There are, however, three main gaps.

First, the studies summarised here have typically focused on specific sectors or physical hazards on the land. While these were all assumed to be important, they were not selected on the basis of their relative contributions to climate change risk in the UK and do not provide a comprehensive coverage. For example, no studies have yet published indicators relating to potential risks to the natural environment (except due to wildfire hazard).

Second, most of the assessments so far have focused on the regional and local strands of the UKCP18 projections, which assume a very high rate of increase in future emissions [35, 36]. It is difficult to link these directly to potential changes under lower emissions, following the Climate change Committee's guidance [37] to adapt to a two degree world but prepare for four degrees—although some analysis has been undertaken using subsets of the probabilistic strand [7] or presented impacts by level of warming [9, 13, 23]. In practice, there is little difference between emissions scenarios to the 2040s, compared with the uncertainty range, so the gap is more relevant over the longer term. Also, the regional and local strands used in most studies are based on a climate model with a relatively high climate sensitivity. The use of just a subset of the full suite of UKCP18 projections means that uncertainty ranges are probably underestimated.

Third, with the exception of the agriculturally focused 2021 study by Garry and others [4], there have been few assessments of how compound events and extremes might change in future (e.g. the cumulative impact of wind, rain and storm surges, or hot, dry and high fire danger conditions).

5 CONCLUSIONS

The studies summarised here together enable a consistent assessment of potential changes in climate hazards and resources across the UK using the same underlying climate scenarios, in terms directly relevant to the management of climate risks. Future risk and future impacts depend on how these changes in hazard and resource interact with changes in exposure and vulnerability.

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