Lancashire
Independent Economic Review

Final Report:
Climate Resilience Study

Revision 3.2

ATKINS
Member of the SNC-Lavalin Group

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Client signoff

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Contents

Tables

Figures

Executive Summary

Most local authorities in Lancashire have declared a Climate Emergency with initiatives to meet carbon Net Zero targets[1], increase climate resilience and engage and empower communities to contribute to meeting these goals. The Greater Lancashire Plan will deliver a new economic strategy to transform the region, promoting inclusive economic growth and sustainable development.

Climate resilience is the ability to cope with and recover from *acute physical climate risks*, such as floods, droughts and heatwaves, and *chronic physical risks* such as slower onset temperature change and sea level rise. This Climate Resilience Report is one of four sustainability studies that are collecting evidence to inform future strategies. Embedding climate resilience in the region's economic strategy is important to (i) reduce the potential harm, loss and damage due to the increased frequency of floods, heatwaves and droughts; (ii) identify potential opportunities related to a changing climate, such as an increase in the visitor economy or changes in agriculture and forestry and (iii) deliver co-benefits on infrastructure projects, for example providing greenspace or restoring waterways as part of the region's urban regeneration projects[2]. In addition, early consideration of climate change, natural capital and social value can help to secure investment from sources of sustainable finance, as it makes the region lower risk and more attractive to potential inward investment.

Our approach has focused on presentation of UK Climate Projections 2018 for Lancashire along with a range of policy-relevant climate indicators related to health and wellbeing, energy demand, transport and agriculture, using research from the UK Climate Resilience programme. In addition, we take a snapshot of the level of preparedness of the region based on interviews and literature review. More work is needed to mainstream climate resilience, but this report provides climate data and information to inform policies, strategies and enable climate change to be integrated into the region's long term plans.

Key findings (under the 4°C warming scenario)

4 °C warming	>25 °C average summer maximum	>37 °C Potential for record breaking high temperatures
2.5 x increase in river floods	Increased demand for water	2 x increase in hydrological droughts
Up to 1 m sea level rise	30% Reduction in winter heating by the 2050s	8 heat alerts per year
10 x demand for cooling in summer by the 2050s	40 days per year with adverse weather for railways	30 days Lost milk production due to heat stress in cattle

Note: Based on the UKCP18 'high' RCP 8.5 climate change scenario and mostly central estimates of future changes, with the exception of sea level rise, which is an upper estimate.

[1] For example, Lancaster City Council declared a Climate Emergency in July 2019 Climate Emergency - Lancaster City Council. Currently all but one of the Lancashire District Councils and Unitary Authorities have declared a Climate Emergency.
[2] The Climate Change Committee's Independent Assessment for the Climate Change Risk Assessment 3 highlighted a strong case for early investment in climate adaptation and resilience.

Climate trends

- **Climate change trends are already clear in Lancashire.** Average annual temperatures in the Northwest of England are already around 1.5°C higher in the 21st century compared with the end of the 19th century[3].
- At Heysham, **recent rates of sea level rise are around 4 mm/year,** a faster rate of change than the long term average for the UK (1.4 ± 0.2 mm/year), and consistent with the upturn the global average sea level rise since 1990.

Climate change

- **Lancashire's climate is projected to be significantly warmer by the 2080s**, with annual average temperatures increasing by 4°C above recent baseline (1981-2000) across the region under a 'high' scenario, along with a 20-30% increase in winter rainfall and a 20-40% decrease in summer rainfall.
- **Floods:** There is likely to be significant increase in rainfall intensity, with a two-fold increase in the frequency of very heavy rainfall, leading to more frequent river flooding across the county. Without enhanced adaptation this will lead to an increase in damage and losses due to flooding.
- **Drought:** There could be twice as many hydrological droughts (duration of low river flows) by the end of the century, which has potential impacts on public water supply and the environment.
- **Sea level rise:** Projected rates of sea level rise are higher than in previous assessments and could rise by 1 metre under the RCP8.5 scenario. Even under lower emissions, there will be some increase in sea level rise. This is likely to have associated impacts onshore when combined with increased storm events.
- **Health and well-being:** Climate change is projected to increase the frequency of heatwaves and decrease cold weather events. West Lancashire, the Borough of Chorley, South Ribble, the City of Preston, and Blackpool could experience up to 5 heatwaves and 8 heat-health alerts a year, with an average of 3 and 5 across the whole of Lancashire respectively.
- **Energy use:** Climate change is projected to decrease days requiring heating across Lancashire; by the 2050s, these could be 30–40% lower than at present. Over the same time period there will be a more than tenfold increase in the days where cooling is required.
- **Transport:** Climate change is projected to increase risks for transport systems due to high temperatures and extreme weather events. Currently, the incidents of melting roads in Lancashire are rare but, after 2050, they could occur up to 4 times a year in West Lancashire, Chorley, South Ribble and City of Preston. The number of rail adverse weather days could increase from current 20 to as high as 70 each year.
- **Agriculture:** an earlier spring, longer growing season and increase in growing degree days are likely to benefit pastures but more agricultural droughts and higher soil moisture deficit may adversely affect arable land. Higher temperatures are likely to impact on livestock, pests and diseases as well as milk production.

How prepared is Lancashire?

- **Lancashire's local authorities** have a 'medium' level of adaptive capacity and level of preparedness for managing climate risks based on Atkins' Climate Adaptation Preparedness Framework. While there are many examples of a high awareness of climate change in the management of road networks, building services and public health, more can be done to promote greater climate resilience.
- **Government departments, utilities and the private sector are already adapting to future climate change.** The Environment Agency, United Utilities, Highways Agency and Network Rail incorporate climate change in their long-term plans, particularly for new infrastructure. The biggest challenge is likely to be funding and whether the required adaptation funding can keep pace with climate change.
- **Lancashire already has many good examples of climate change adaptation.** These include public health warning services for heatwaves, as well as enhancing natural capital as part of peat restoration projects and coastal flood risk management schemes.

Next Steps

- **Climate resilience is a key sustainability theme.** We anticipate that the findings of this work will be integrated into the Greater Lancashire Plan. Some recommendations are made to extend this review to support ongoing work programme.

[3] Based on Met Office HadUK data using annual average temperatures for 2001-2019 minus the average for 1884-1900.

1. Introduction

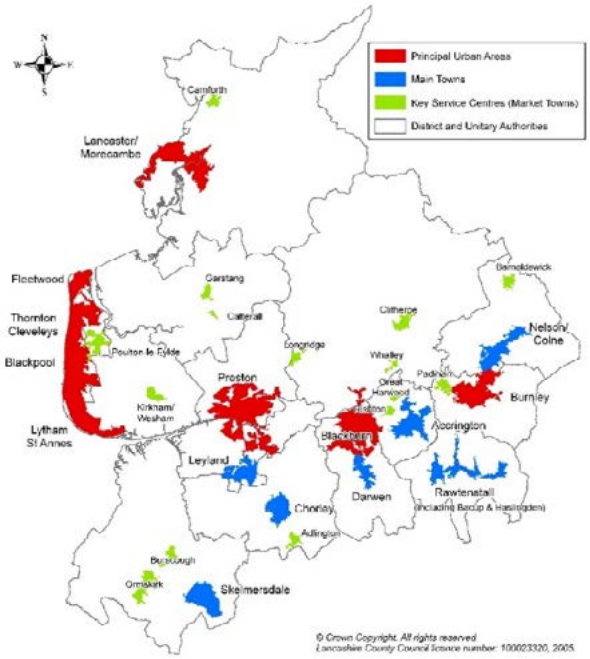
In 2009 the Lancashire Climate Change Partnership developed a Climate Change Strategy[4] with a long-term vision to transform the region to a low carbon economy that is well adapted to future climate change. Since then, scientific evidence has shown increased rates of warming, higher rates of sea level rise and increased risk for vulnerable communities around the world[5]. During 2019 and 2020, Lancashire County Council and local authorities[6] across the region declared a Climate Emergency with initiatives to meet carbon Net Zero targets, increase climate resilience and engage and empower communities to contribute to meeting these goals.

Through an Independent Economic Review (IER), Lancashire is developing a new economic strategy to transform the region, promoting inclusive economic growth and sustainable development. Lancashire has one of the largest local economies in the North of England, with 52,000 businesses generating around £30bn per year. The county is a recognised world-leader in aerospace, advanced engineering and manufacturing, energy, and higher education excellence. The region is connected to London by train, linked to the rest of the UK by five major motorways and to the rest of the world via Manchester and Liverpool airports[7]. Sustainability, including action on climate change, is an integral part of the Greater Lancashire Plan.

1.1. Climate vulnerability context

Lancashire is a large county with a diverse landscape, rooted in a rich industrial tradition, with densely populated urban centres which are themselves surrounded by outstanding countryside and coastal areas[8]. The urban centres include some of the most deprived areas of the UK[9], while rural areas include both high quality agricultural land and coastal sites with international environmental designations[10].

Figure 1-1 – Principal urban areas and towns in Lancashire

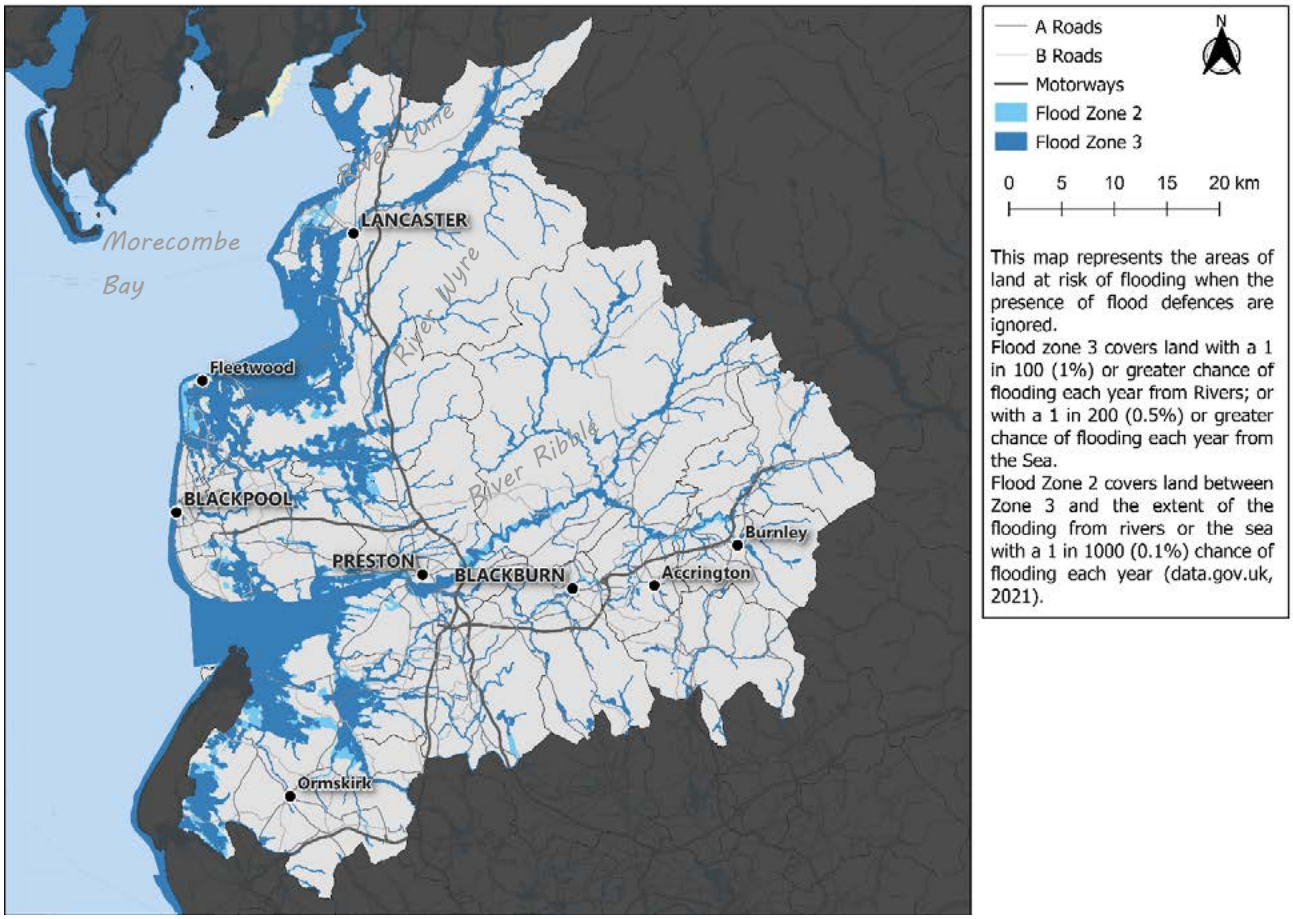


The region is exposed to coastal flooding, river and surface water flooding (Figure 1-2) as well as water scarcity and drought. While average and maximum summer temperatures are lower than the south east of England, there is still exposure to heatwaves, a hazard that is already becoming more frequent due to climate change. Some coastal and urban communities, including elderly people and disadvantaged groups, have greater exposure and sensitivity to climate hazards due their location along the coastline or in urban centres (Section 3).

The sensitivity of the region's economic sectors to climate change varies, with the highest sensitivities related to agriculture, forestry and fishing, water supply and sewerage, transport and energy. The built environment in all sectors, including advanced manufacturing and health and social care, is sensitive to floods, heatwaves and drought. There are also clear and strong interdependencies between sectors and the economic success and sustainable development of the region requires action on climate resilience as well as achieving Net Zero targets.

[4] Lancashire climate change strategy - Lancashire County Council
[5] Global assessments include the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report — IPCC as well as subsequent special reports on ice melt and sea level rise. In the UK, the Climate Change Risk Assessment 2012 and 2017 have described the impacts in the UK (see next section).
[6] For example the city council declared a Climate Emergency in July 2019 Climate Emergency - Lancaster City Council
[7] Lancashire Enterprise Partnership - A strategic collaboration between business, universities and local councils which directs economic growth and drives job creation (lancashirelep.co.uk)
[8] Lancashire Strategic Economic Plan (LSEP). A Growth Deal for the Arc of Prosperity. March 2014
[9] https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015
[10] Environment and conservation maps - Lancashire County Council

Figure 1-2 – Coastal and River floodplains in Lancashire



Source: Environment Agency

The exposure to coastal and river flooding is greatest in the coastal towns, around Morecombe Bay and the Ribble Estuary and along the region's major rivers, the Lune, Wyre and Ribble. Other vulnerability hot spots include (i) sensitive upland areas, including moorlands exposed to wildfires; (ii) urban centres exposed to poor air quality and overheating risks and (iii) lowland rural areas exposed to water resources drought and agricultural impacts (see Section 3.2 onwards).

1.2. Climate resilience

Climate resilience is the ability to cope with and recover from *acute physical climate risks*, such as floods, droughts and heatwaves, and *chronic physical risks* such as slower onset temperature change and sea level rise. Embedding climate resilience in the region's economic strategy is important to:

(i) Reduce the potential harm, loss and damage due to the likely increase in the frequency of floods, droughts and heatwaves due to climate change, which can damage both the economy and well-being.

(ii) Identify potential opportunities related to a changing climate, such as an increase in the visitor economy or changes in agriculture and forestry.

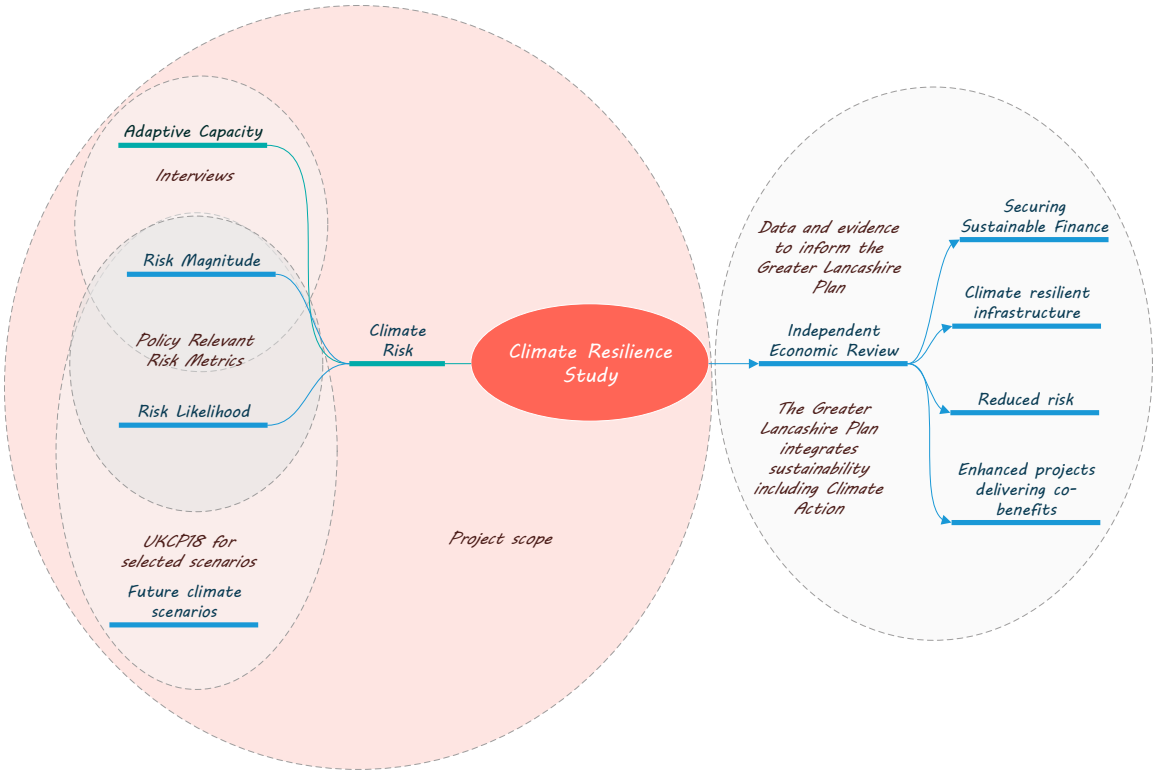
(iii) Deliver co-benefits on infrastructure projects, for example providing greenspace or restoring waterways as part of urban regeneration projects that reduce flood risk and enhance amenity, biodiversity, health and well-being.

In addition, early consideration of climate change, natural capital and social value can help to secure investment from sources of sustainable finance as it makes the region lower risk and more attractive to potential inward investment.

1.3. Our approach

Lancashire County Council, Blackpool Council and Blackburn with Darwen asked Atkins to provide a climate change resilience study to assess the implications of the latest UK Climate Change Projections 2018 and to provide evidence that can inform the Lancashire Economic Strategy. The study aims to assess the sensitivity of the physical, social, environmental and economic systems in Lancashire to a range of hazards, including flooding, heatwaves and droughts, and the preparedness of organizations to adapt and cope with future. Our approach is centred on presentation of policy relevant climate metrics, developed by the UK Climate Resilience research programme[11] and based on the Met Office UK Climate Change Projections 2018[12] (UKCP18). This work is supported by literature review, interviews with local authority officers and identification of existing case studies of climate adaptation change.

Figure 1-3 - Scope of the Climate Resilience Study



The report is structured as follows:

- Section 2 provides a short summary of historical changes in climate in the North West and significant hazard events that have impacted the region;
- Section 3 reviews studies on the impacts of climate change in the UK, drawing out relevant data and information for the North West of England or Lancashire;
- Section 4 introduces the UKCP18 climate projections and presents a range of metrics based on these scenarios;
- Section 5 summarises information on how prepared the region is for future climate change;
- Section 6 provides some adaptation examples based on existing projects;

[11] Arnell et al., 2020; Arnell and Freeman, 2021a; Arnell and Freeman, 2021b. See Section 4.
[12] Lowe et al., 2019. UKCP18 Science Overview Report. November 2018 (Updated March 2019)

- Section 7 summarises adaptation principles and potential actions that could be undertaken to make steps towards a 'Climate Resilient Lancashire'

Further detailed analysis is included in Appendix A and selected data sets gathered for the study are available from the authors.

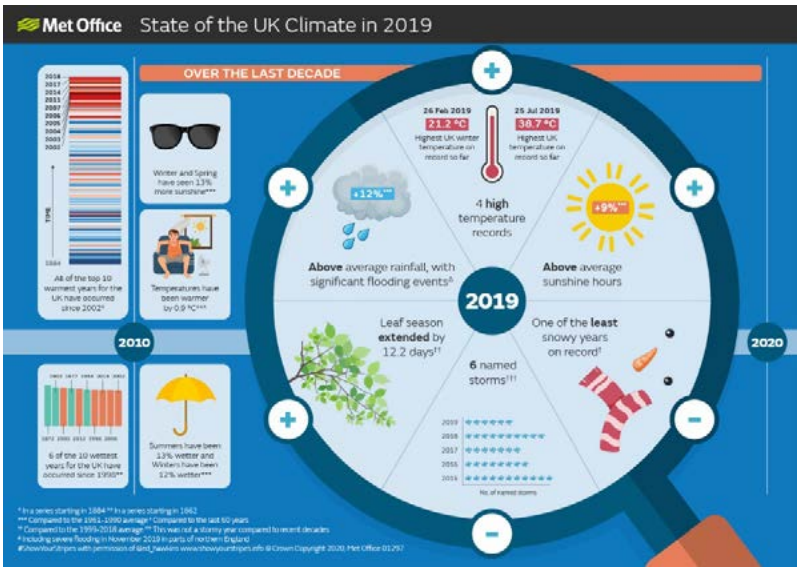
1.4. Related sustainability studies

This study is one of four studies that will inform the Greater Lancashire Plan. The other related sustainability studies are:

- Lancashire Net Zero Pathway Options, which explores different pathways towards reaching the region's ambitious net zero targets (Atkins)
- Lancashire State of the Environment Report, which provides and assessment of the current environmental status and how this has changed over the past 20 years (Jacobs)
- Lancashire Sustainable Energy Report, which updates an assessment of the potential for renewable energy across the region (Jacobs)

2. Climate trends

The UK climate is already changing; over the last decade the UK has experienced warmer conditions, with four high temperature records, an increase in sunshine hours and some significant flood events[13].



Taking a longer term view, the UK has warmed by more than 1°C since pre-industrial times, sea levels have risen by 16cm since 1900 and the likelihood of hot summers has doubled[14].

Key finding: Average annual temperatures in the North West of England are already around 1.5°C higher in the 21st century compared with the end of the 19th century[15].

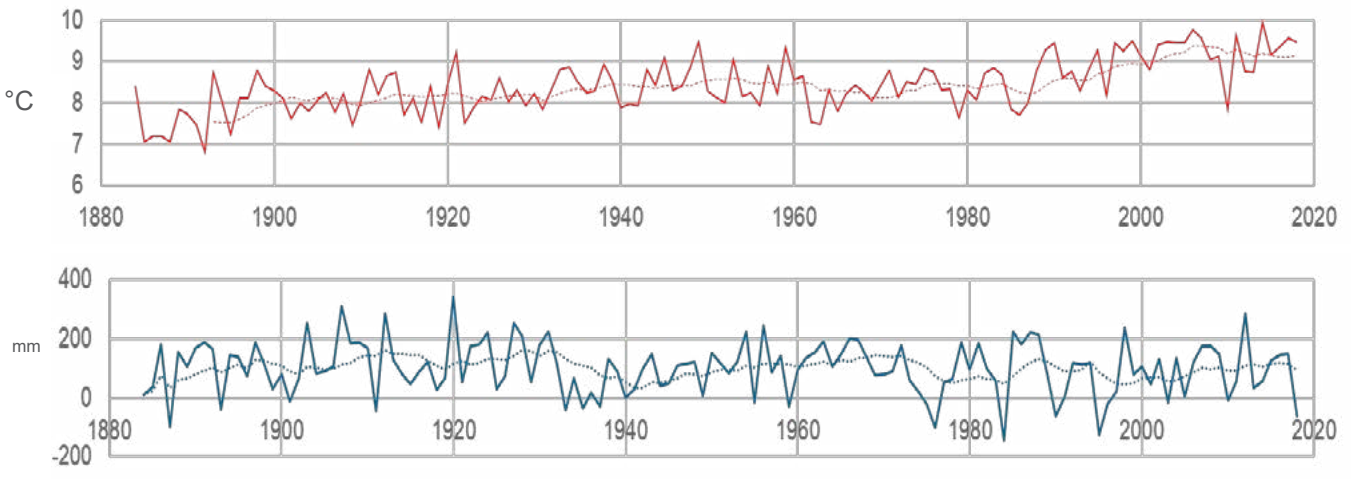
The pace of change in temperature has accelerated in recent decades, consistent with the findings from climate models[16].

Annual average rainfall in the North West, however, has not yet changed significantly[17]. The year-to-year variability has increased (with more dry and wet years) and some research shows an increase in the change of heavier rainfall events[18]. The greatest change in seasonal rainfall trends is an increase in winter rainfall, due to an intensification of heavy rainfall events.

Additionally, the amount of water lost to evaporation is likely to have increased in step with the observed increases in temperature. Our estimates[19] show an increase in potential evapotranspiration in North West England, which has implications for the water balance and water availability, particularly in spring and summer.

[13] State of the UK Climate - Met Office and Kendon, E. et al., 2019. State of the UK Climate 2019. Int J Climatol. (below).
[14] Climate Change Committee (2021). UK Climate Risk [online]. Available at: https://www.ukclimaterisk.org/ [Last Accessed: 07-05-2021]
[15] Based on Met Office HadUK data using annual average temperatures for 2001-2019 minus the average for 1884-1900.
[16] Karoly and Stott (2006). Anthropogenic warming of central England temperature. Available at: https://rmets.onlinelibrary.wiley.com/doi/pdf/10.1002/asl.136
[17] Analysis completed by Atkins, using HadUK precipitation data
[18] Kendon et al. (2019). State of the UK climate 2018. Available at: https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/joc.6213
[19] Atkins research for United Utilities, using monthly average temperatures from the HadUK-Grid North West England monthly dataset and the Oudin formula (Oudin et al., 2005) to calculate potential evapotranspiration.

Figure 2-1 - Average annual temperature and Spring/Summer water availability in North West England



Source: Met Office HadUK data for the North West of England; Atkins analysis of the annual and seasonal water balance 1884 to 2018

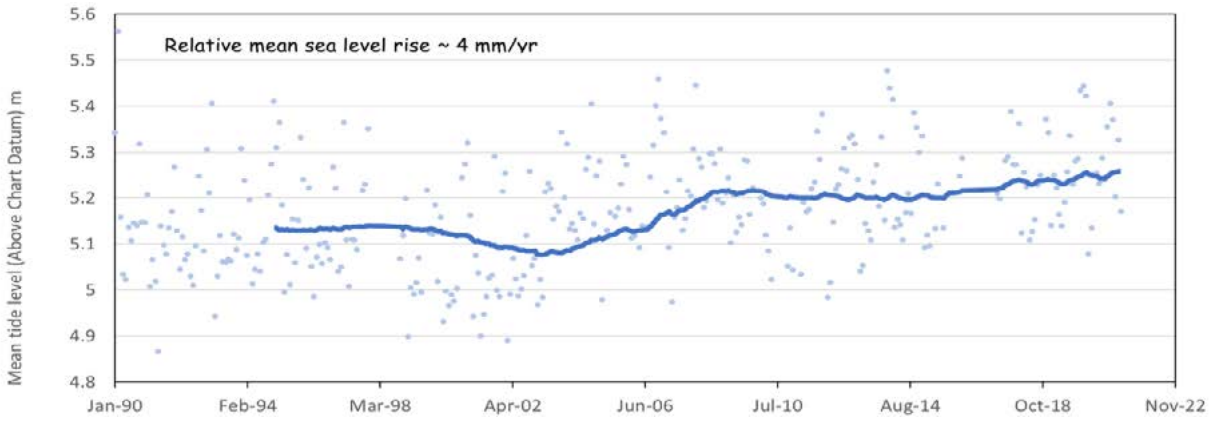
2.1. Sea level rise

Sea level rise is one of the clearest signals of climate change and recent international research has indicated that rates of rise are much higher than in previous assessments[20].

In the UK, observed long term trends indicate sea level is rising nationally at a rate of 1.4 mm/year (± 0.2 mm)[21], with high rates in the south east and lower rates in Scotland due to relative land movements.

Key finding: At Heysham in Lancashire recent rates of sea level rise are around 4 mm/year, a faster rate of change than the long term average for the UK (1.4 ± 0.2 mm/year), consistent with the upturn the global average sea level rise since 1990[22].

Figure 2-2 - Average monthly tide levels at Heysham with a long term moving average to indicate trends



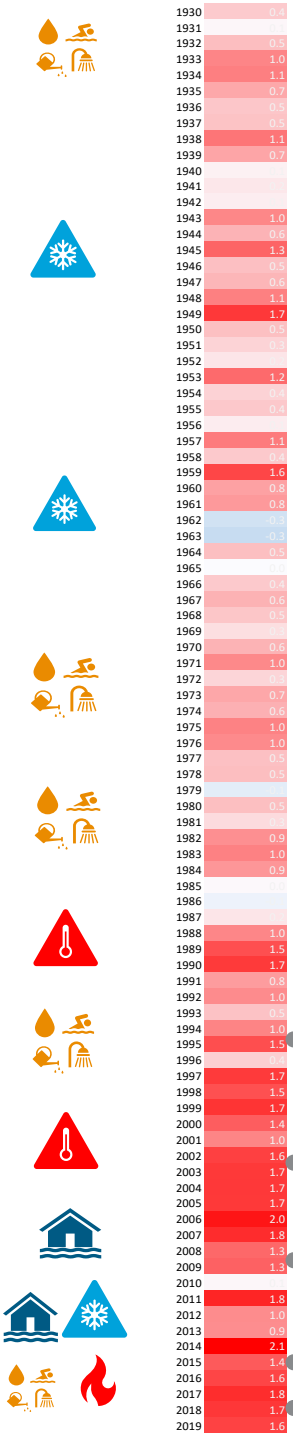
Source: UK Tide Gauge Network, provided by the British Oceanographic Data Centre (Note that one high tide level from 2015 is excluded from the graph and this analysis is illustrative only).

[20] The recent IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) reported that *"sea level continues to rise at an increasing rate. Extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (at least once per year) at many locations by 2050 in all RCP scenarios, especially in tropical regions (high confidence)"*

[21] Church et al. (2013). Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf

[22] Holgate, S.J. and P.L. Woodworth, 2004: Evidence for enhanced coastal sea level rise during the 1990s. Geophysical Research Letters, 31, L07305, 4 PP.

Figure 2-3 - Historic climate events in Lancashire alongside the North West of England 'Climate Stripes' showing average warming above late pre-industrial period[23, 24, 25, 26,27]



1933/34 Drought

1947 Big Snow

Two months of freezing temperatures and snow. National Grid could not supply sufficient electricity and Blackpool was one of the towns chosen by the Government to have power cuts to reduce coal consumption in the power stations.

1963 Coldest Winter

Blizzards, snow drifts, blocks of ice and temperatures lower than -20°C were recorded. Roads and railways were blocked, telephone lines brought down and some villages were left cut off for several days. The snow was so deep farmers could not get to their livestock and many animals starved to death.

1975/1976 Drought

1984 Drought (a key event for water resources planning)

1990s – Regular exceedance of 1°C above pre-industrial in individual years

1995 Drought

2003 Heatwave in France and South East England; Drought Permits in NW

2009 Cumbria Floods: Dozens of people forced to leave homes with 8 in of rain and 6 severe flood warnings.

2015 Storm Desmond Cumbria Floods: More than 15 severe flood warnings. More than 43,000 homes suffered from power cuts, whilst an estimated 5,200 homes were affected by flooding in Cumbria and Lancashire. Power was lost at 42,000 properties across Lancaster, Morecambe, Heysham and Carnforth. Flooding continued due to subsequent storms.

2018 Beast from the East Yellow weather warning with temperatures reaching -10°C. Widespread problems on the roads of Lancashire, with more than 50 schools closed.

2018 Low Spring water resources availability

2020 Major wildfire on Darwen Moor[28]

[23] http://news.bbc.co.uk/local/cumbria/hi/people_and_places/newsid_8378000/8378388.stm
[24] https://www.bbc.co.uk/news/uk-35023558
[25] https://www.lep.co.uk/news/traffic-and-travel/how-lancashire-coping-beast-east-340202
[26] https://www.metoffice.gov.uk/weather/learn-about/weather/case-studies/severe-winters#:~:text=With%20temperatures%20so%20cold%20the,and%20the%20coldest%20since%201740 .
[27] Hawkins, E.; Craig, P. (2019): Meteorological observations recovered by the Weather Rescue project. Centre for Environmental Data Analysis, date of citation. http://catalogue.ceda.ac.uk/uuid/56c03beb2e11472d87d547ea53c95f51
[28] Lancashire moorland fires blamed on BBQ and litter - BBC News

3. The Potential Impacts of Climate Change in Lancashire

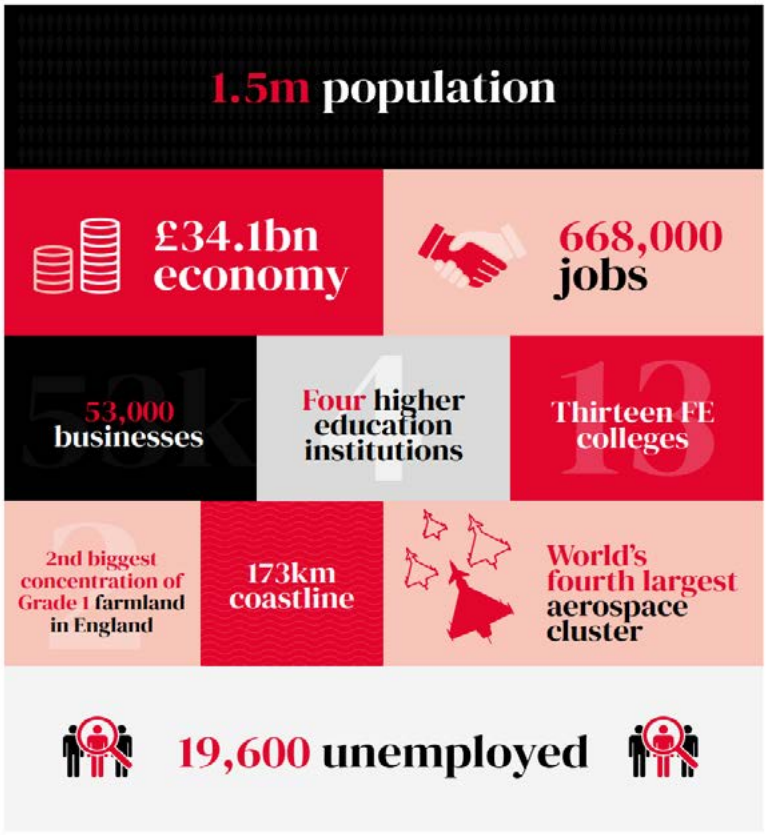
3.1. Socio-economic context

3.1.1. Economy

Lancashire has a population of around 1.5 million people with a strong local economy, generating around £34 billion per annum. The region's strongest economic sectors are aerospace, with the 4th largest aerospace cluster in the world, advanced manufacturing, the automotive industry and nuclear energy. Food manufacturing, the visitor economy and the financial and professional service sectors are all important for employment and productivity but have provided fewer opportunities for economic growth over the last decade.

Covid-19 has impacted the economy but the region has implemented an immediate recovery plan focused on re-opening businesses, the visitor economy and initiatives in the aerospace and manufacturing sectors. This includes over £62 million investment in priority infrastructure projects, including enabling infrastructure for the Eden Project North and urban regeneration projects. In order to 'build back better' these projects should consider climate change and provide opportunities to enhance local communities and the environment.

Figure 3-1 - Lancashire Overview [29]



Source: Various, including ONS population estimates, ONS Regional Accounts, ONS Business Register and Employment Survey, ONS Annual Population Survey, DEFRA

The Greater Lancashire Region's 173km of coastline includes important industrial and environmental assets. The port of Heysham is an important UK offshore supply base serving the offshore gas sectors in the Irish Sea. The Heysham 1 and 2 power stations represent one of the largest concentrations of power generation in the UK, with planned decommissioning from 2024 for Heysham 1[30] and 2030 for Heysham 2[31]. The economy depends on critical infrastructure including the energy system, water system, transport system, healthcare and schools that need to continue to operate effectively during extreme events and under future climate change scenarios.

[29] *Sources: Lancashire Independent Economy Review Interim Report.* LIER_InterimReport2021_v1.pdf (lancashireier.org)

Also see Redefining Lancashire: Our Approach to Recovery, 25 June 2020. https://www.lancashire.gov.uk/media/917897/redefining-lancashire-our-approach-to-recovery-25-june-2020.pdf

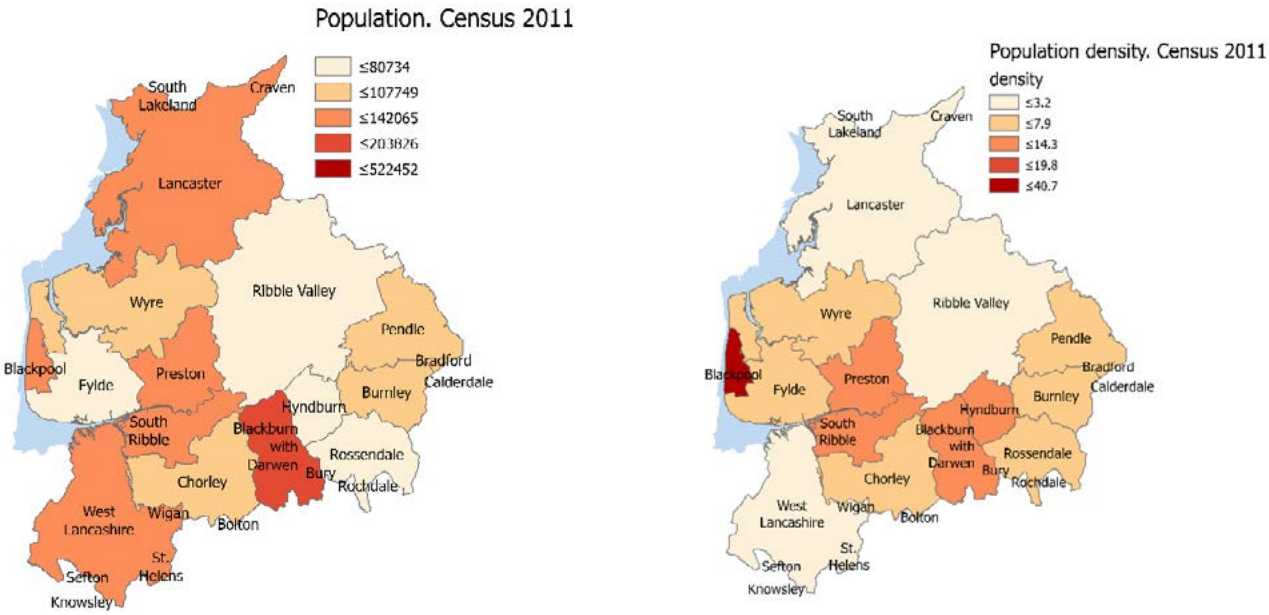
[30] ONR - Sites that we regulate: Heysham 1

[31] ONR - Sites that we regulate: Heysham 2

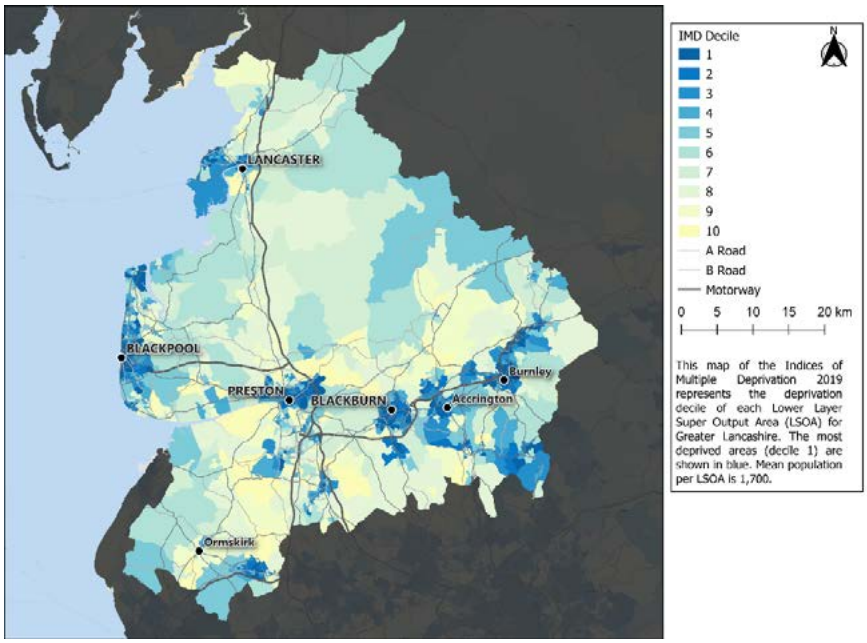
3.1.2. Population and socio-economic data

The region's highest populations are in Blackburn and Darwen and the highest densities are in Blackpool. By contrast the Ribble Valley and West Lancashire have a lower population densities (Figure 3-2).

Figure 3-2 - Lancashire population statistics and Index of Multiple Deprivation (IMD)



Notes: Local authority population from Census 2011. Left – number of residents. Right – population density. Contains OS and ONS data © Crown copyright and database right 2021. Below - IMD2019 map project in QGIS3, created by Alasdair Rae, (8 Oct 2019) OS OpenData Licence. Contains National Statistics data Crown copyright and database right 2019 Indices of Deprivation 2019 resources (shef.ac.uk)



Lancashire as a whole has average total incomes and employment incomes that are marginally lower than the national average. Self-employment incomes are notably lower than the national average and pension incomes are close to the national average (2014/2015 data)[32]. Health, education and skills, poverty, and deprivation are all regarded as major issues in Lancashire[33].

Some of Lancashire's towns are still blighted by the legacy of an earlier industrial era and there are some pockets of deprivation. Based on the Index of Multiple Deprivation (IMD), seven areas - Blackpool, Burnley, Blackburn

[32] Personal incomes - Lancashire County Council
[33] Key finding 4 IER, 2021 LIER_InterimReport2021_v1.pdf (lancashireier.org)

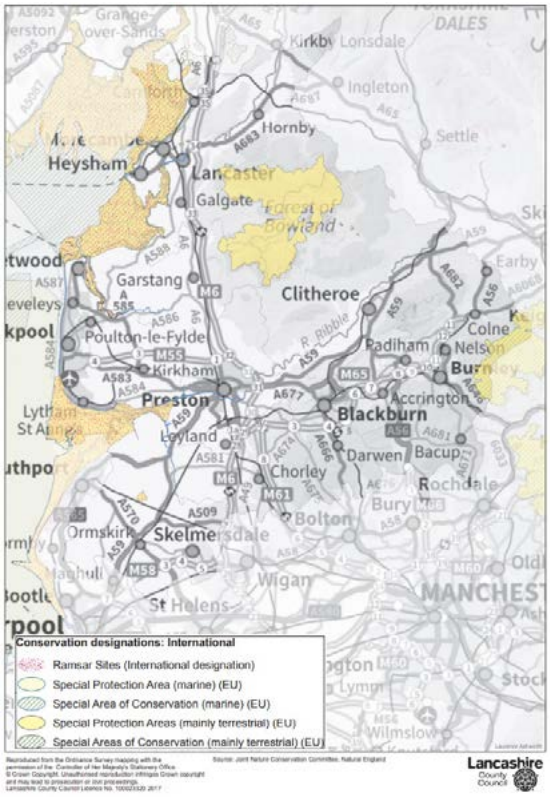
with Darwen, Hyndburn, Pendle, Lancaster and Preston - include low ranking wards where the level of deprivation is particularly high[34]. Lancashire has significantly more deprived areas than the national average based on key indicators[35], for example 13% of the population are income deprived and 17% of children live in income deprived families. A large proportion of the elderly population lives in coastal areas. The higher hazard exposure of both deprived and elderly communities is particularly relevant for understanding climate risks because those communities have particular needs, e.g. social care and health assets, but lower capacity to cope with climate change.

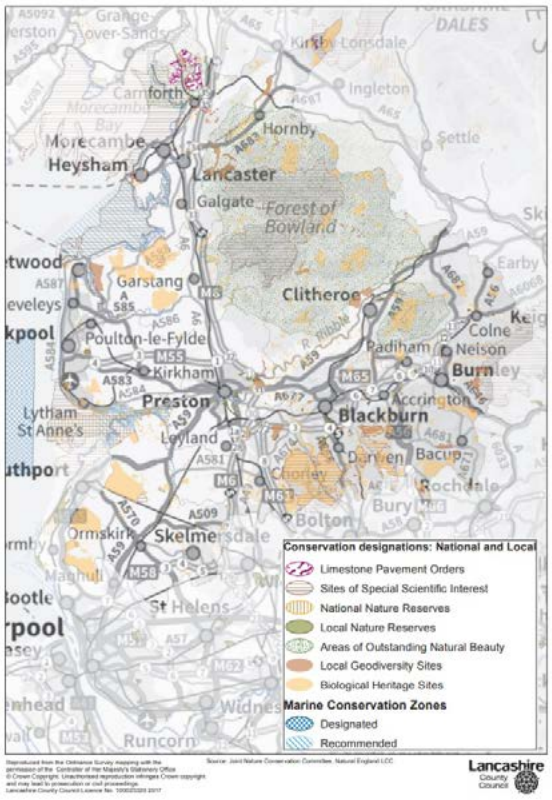
3.1.3. Environment

With an area of more than three thousand square kilometres[36], Lancashire provides a diverse environment including coastal areas, urban areas and fringes and rural uplands and lowlands. The county includes international designations for marine and terrestrial Special Protection Areas and Special Areas of Conservation and incorporates parts of two designated areas of outstanding natural beauty (Forest of Bowland and Arnside/Silverdale) (Figure 3-1).

Air quality is generally good in coastal and rural areas but there are areas of poor air quality in some towns due to emissions from transport and industry. Bathing water quality has improved significantly over the last two decades, reflecting the high standards set by the Water Framework Directive, but there are still some challenges related to river water quality. Further details on the State of the Environment in Lancashire are presented in a separate report[37].

Figure 3-3 – International, national and local terrestrial environmental designations





[34] deprivation-2015-la-summaries.pdf (lancashire.gov.uk)
[35] Lancashire County Council (2021). Lancashire Insight. Available at: Lancashire Insight - Lancashire County Council [Accessed: 11/05/2021].
[36] Overview - Lancashire County Council
[37] Jacobs, 2021, State of the Environment Report

3.1.4. Adaptive Capacity

Adaptive Capacity is the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences[38]. Hallmarks of high adaptive capacity include a strong research base and collaboration between institutions. In terms of the region's adaptive capacity and ability to respond to climate change, it has a strong partnerships and collaboration between the Lancashire's local authorities and national government agencies, as well as leading research and innovation assets including Lancaster University, University of Central Lancashire (UCLan) in Preston and Burnley, and Edge Hill University in West Lancashire. The level of preparedness of the County Council is discussed in Section 5.

3.2. Overview of climate change risks and opportunities

Based on several previous studies of climate change impacts and adaptation in Lancashire or the North West of England, the most important climate change impacts for the region are as follows[39]:

- An increase in the risk of flooding and coastal erosion
- Increased pressure on drainage systems
- Winter storm damage
- Habitat loss
- Summer water shortages and low stream flows
- Increased subsidence risk in subsidence prone areas
- Increased demand for summer cooling
- Increasing thermal discomfort in buildings
- Health impacts e.g. related to an increase in heatwaves or mental health impacts of flooding.

Coastal and rural upland regions have been considered to be most susceptible to climate change[40], as sea level rise and rising temperatures can adversely affect valued habitats in these areas, e.g. through 'coastal squeeze' reducing the space available or vegetation loss and other effects. Table 3-1 presents a summary of climate change risks and opportunities in Lancashire. The downside risks are significant; however, these studies have also highlighted opportunities for the visitor economy, farming and reduction in winter fuel poverty. Information on the supporting literature review can be found in Appendix A.1.

3.3. UK Climate Projections 2018

Previous assessment of climate change and risks in Lancashire were based on the UK Climate Projections 2009 (UKCP09) or even earlier assessments. The Met Office published a new set up projections in 2018 with additional products throughout 2019[41].

The main differences between UKCP18 and the previous scenarios used in the above assessments are higher rates of sea level rise, marginally higher rates of warming and increases in summer rainfall intensity. Simplified information on the climate scenarios is available from Met Office/BBC portal[42], but this project used data from the UKCP18 User Interface, CEDA research archive and research studies from the UK Climate Resilience programme. Information on the metrics for future climate change scenarios is presented in Section 4.

[38] BSI_EN ISO 14090:2019 with definition adapted from IPCC, 2014
[39] Ordnance Survey (2010). Green infrastructure: How and where can it help the Northwest mitigate and adapt to climate change? Available at: http://www.greeninfrastructurenw.co.uk/resources/GI_How_&_where_can_it_help_the_NW_mitigate_and_adapt_to_climate_change.pdf
[40] Sustainability North West (1998). Climate Change Impacts in the North West of England. Available at: https://ukcip.ouce.ox.ac.uk/wp-content/PDFs/NW_summary.pdf
[41] About UKCP18 - Met Office
[42] What will climate change look like in your area? - BBC News

3.4. UK Climate Change Risk Assessment

The Climate Change Act 2008 requires the Government to lay before Parliament a five-yearly assessment of the UK's current and projected future risks from climate change. Climate Change Risk Assessment 2 (CCRA2) was the most recent assessment[43], however CCRA3 was published during this study. CCRA2 informed development of the government's second National Adaptation Programme (NAP) for the period 2018-2023[44]. The 6 focus areas of CCRA2 and the NAP are all relevant to Lancashire:

- Flooding and coastal change risks to communities, built environment and infrastructure
- Risks to health and well-being and productivity from high temperatures
- Risk of shortages in the public water supply with impacts on freshwater ecology
- Risks to natural capital including terrestrial, coastal, marine and freshwater ecosystems, soils and biodiversity
- Risks to domestic and international food production and trade
- New and emerging pests and diseases, and invasive non-native species affecting people, plants and animals.

The Climate Change Committee's Independent Assessment to support the CCRA3 was published in June 2021[45]. It reports that the none of the risks identified previously have reduced in magnitude; in general terms the pace of adaptation was seen as too slow to keep pace with the rising risks due to climate change. The risks that require urgent action included risks affecting the natural environment, including its ability to store carbon under warmer and drier conditions; risks affecting the reliability of the power system, particularly due to the increased dependence on electricity over gas and the risks to productivity from extreme heat across the UK. Further details from the CCRA evidence are included in Appendix A.1.

[43] https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-2017
[44] national-adaptation-programme-2018.pdf (publishing.service.gov.uk)
[45] UK Climate Risk includes the technical reports and sector briefings

Table 3-1 - Climate change risks and opportunities in Lancashire[39,40,46]

Landscape	Risks	Opportunities
Coastal	Flooding Heavy beach erosion Loss of feeding grounds for birds Shift in siltation patterns More regular dredging to clear siltation from waterways Loss of temperate marine coastal ecosystem High expenditure on coastal defences Disruption of ports, shipping industry, fisheries, and coastal resorts	Coastal zone regeneration Potential for evolution of the tourism sector/ different tourism opportunities Expansion of more moisture dependent species Fleetwood Nautical Campus to train future generations of seafarers to cope with climate change conditions, e.g. higher wind speeds, greater precipitation and increased storminess.
Urban Core and Fringe	Urban 'heat islands' and associated health risks and lost productivity Increase in cooling demand Increase in water and electricity demand Increase in need for shelter from sun Impacts on parks and gardens Water shortages for watering gardens Rise of water tables Flooding due to surface water and sewer flooding Sewer overflows polluting aquatic environments Damage to buildings and other infrastructure from storms Invasive pests and disease	Potential for more outdoor activities and events Potential for healthier outdoor and more active lifestyles Economic benefits for leisure industry Greater potential for community forests Lower winter heating bills Diverting investments towards renewable energy generation for increasing fuel use, either locally or with offshore wind farms in the NW coastal area or Irish Seas
Rural Lowland	Additional stress to plant and animals Vegetation change, invasive species, pests and disease Loss of habitat and species Water supply shortages Erosion and cracking of land over summer Higher soil moisture content over winter Risk of stream, river, sewer floods, and pollution runoff Potential damage to agriculture from storms and heatwaves	Potential for new crops for farming Potential for recreational activities and associated economic benefits More rapid vegetation growth and longer growing season for some species
Rural Upland	Species loss and migration Water supply and transfer affected Low water levels and quality Vegetation loss Flash floods Invasive species and diseases Wildfires Soil erosion Release of carbon from peatlands Potential damage to agriculture from storms and heatwaves	Potential for new crops for farming Potential for recreational activities and associated economic benefits More rapid vegetation growth and longer growing season for some species

Sources: Sustainability North West (1998), Lancashire Climate Change Partnership (2009)

[46] The Lancashire Climate Change Partnership (2009). The Lancashire Climate Change Strategy 2009-2020. Available at: https://www.lancashire.gov.uk/media/190306/Lancashire_Climate_Change_Strategy_2009_2020.pdf

4. Climate Change Indicators

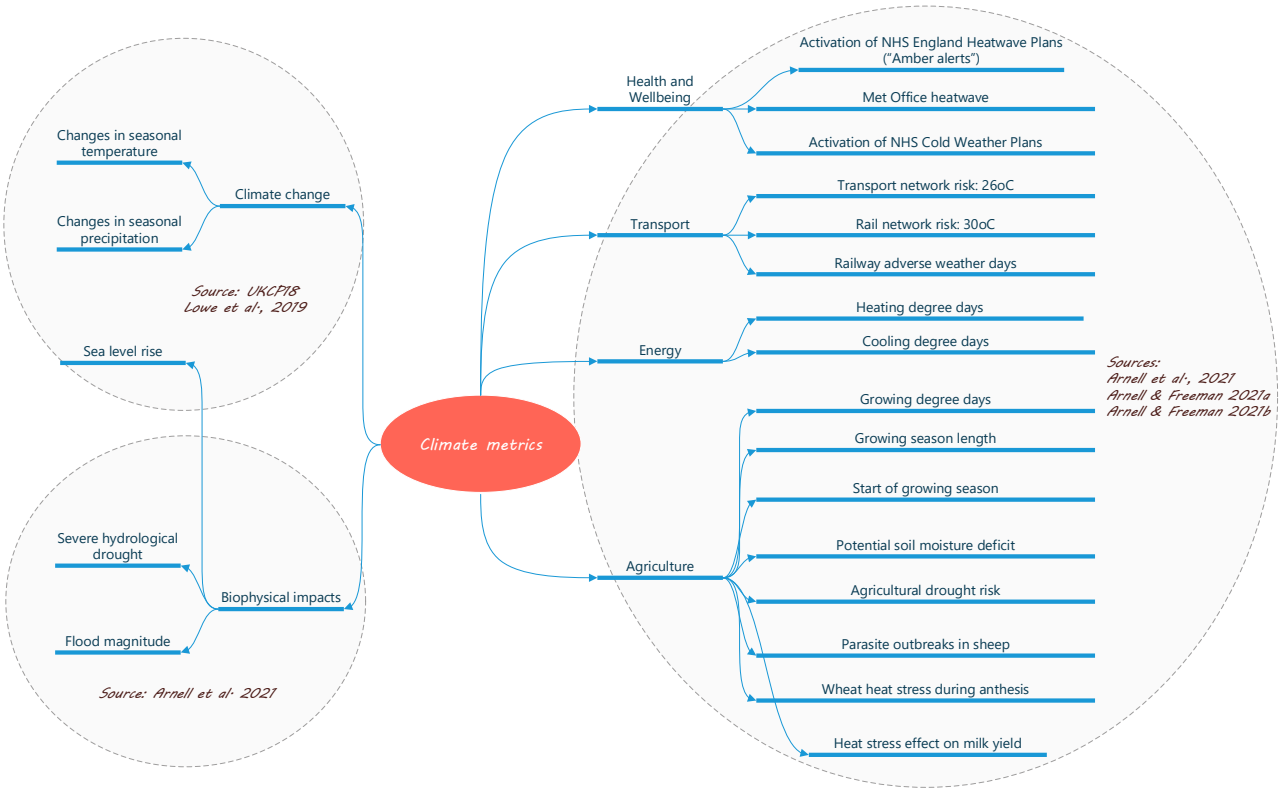
4.1. Introduction

This section includes Atkins' analysis of climate data from the UK Climate Projections 2018 (UKCP18) as it relates to the relevant sectors and geographies of Lancashire. It includes projected climate conditions and sea level rise based on UKCP18 along with climate indicators relevant for understanding impacts related to health & wellbeing, energy use, transport, agriculture, and droughts and floods. These indicators are based on research completed as part of the UK Climate Resilience programme[47].

4.2. The development of climate indicators

The climate metrics developed are summarised in Figure 4-1. The assessment is based on changes from the 1981-2000 baseline period using the most appropriate UKCP18 products. Further detailed definitions of each indicator and methodology are included in Appendix A.2.

Figure 4-1 – Climate change information and policy relevant climate metrics



Data sources:

Lowe et al., 2019, UKCP19 Science Overview
Arnell NW et al., 2021. Changing climate risk in the UK: a multi-sectoral analysis using policy-relevant indicators. Climate Risk Management 31:100265
Arnell and Freeman, 2021a. The impact of climate change on policy-relevant indicators of heat extremes in the United Kingdom
Arnell and Freeman, 2021b. The effect of climate change on agro-climatic indicators in the UK Published online: 31 March 2021 Climatic Change (2021) 165: 40 https://doi.org/10.1007/s10584-021-03054-8

[47] Citations as above. Arnell et al., 2021; Arnell and Freeman, 2021a; Arnell and Freeman, 2021b. Work completed by Anna Freeman while working at Atkins with additional interpretation by the project team.

4.2.1. Representative Concentration Pathways

In order to model and predict future climate conditions, assumptions must be made about the many interlinked factors that will influence climate change. Representative Concentration Pathways (RCPs) are a method by which these assumptions, covering economic, social and physical aspects along with technical innovation and attitudes to technology, are captured within a set of scenarios. They are neither policy recommendations nor forecasts but represent a broad range of climate outcomes. By facilitating better interaction between the scientific communities working on climate change, adaptation and mitigation, they enable the costs and benefits of long-term climate goals to be evaluated. RCPs recognise that the identified goals relating to greenhouse gas emissions or mean temperature rise can be reached by more than one underlying socioeconomic scenario[48].

- RCP2.6 represents a future in which the world aims for and is able to implement sizeable reductions in emissions of greenhouse gases. This scenario gives a chance of limiting global average warming in 2100 to near 2°C above pre-industrial levels. As average global temperatures have already exceeded 1.1°C above pre-industrial levels, immediate action is needed globally to limit warming to below 2°C.
- RCP8.5 represents a world in which global greenhouse gas emissions continue to rise and a potential future where the nations of the world choose *not* to switch to a low-carbon future. The average temperature increases associated are much higher than RCP2.6; in the UK, they are likely to rise by more than 4°C by the 2080s.

4.2.2. Achieving Net Zero in Lancashire

The Lancashire Net Zero Study focused on targets consistent with RCP2.6 but it is the global ambition, particularly from the largest emitters of greenhouse gases, that will have the greatest impacts on changes in climate in the UK. Therefore, in order to understand the potential risks for Lancashire, results from RCP8.5 have been used as the basis for much of the assessment with information from other scenarios to provide a broader context. With the current global ambition for greenhouse gas reductions, the most likely scenario is around 3°C warming, and greater efforts are needed to avoid increased risks in the second half of the century.

Most councils in Lancashire have declared a climate emergency. A study has been completed on pathways to Net Zero, which provides an evidence-based assessment of Lancashire's current carbon footprint at territorial level. It has considered different pathways that include robust and realistic interventions that would put the region on track to achieve emission reductions for three possible pathways options: a) 68% by 2030, b) 100% ('Net Zero') by 2030 or c) 78% by 2035. The results will inform the Greater Lancashire Plan, which is currently under preparation.

The assessment includes baseline and Business as Usual emissions calculations, a carbon budget, assessments of existing measures and future intervention options for Net Zero actions across key sectors such as domestic interests; industrial & commercial activities; transport operations; waste management; agriculture, land use and land use change (LULUCF). The commission will also consider residual emissions removal options.

Atkins facilitated a Climate Emergency Officers Group workshop to discuss the proposed route maps and will present the results of the Options Report at the Lancashire Environment and Climate Summit for Lancashire Leaders and other stakeholders planned for the summer of 2021.

[48] Defra, BEIS, Met Office Hadley Centre and the Environment Agency, 2018. UKCP Guidance: Representative Concentration Pathways. www.metoffice.ov.uk

4.3. Climate change in Lancashire

The main changes in future climate for the North West of England, including Lancashire, are as follows (all changes for RCP8.5 unless stated otherwise):

- For the RCP8.5 scenario, the North West of England is likely to warm by more than 4°C by the end of the century (range 2°C - 6°C) above 1981-2000 baseline (Figure 4-2).
- For RCP2.6, the Paris-aligned trajectory, warming would be much lower and remain below 2°C above the 1981-2000 baseline (range 0.3°C – 2.6°C).
- Significantly higher average maximum summer temperatures (June-August), with typical temperatures over 25°C by the end of the century (Figure 4-3). Maximum temperatures (for a single day) could exceed 37°C in parts of Lancashire under this scenario.
- Winters are projected to be warmer and wetter, whereas summers are projected to be hotter and drier than the 1981-2000 period. Seasonal changes in precipitation in the North West are the most extreme changes anticipated in England and Wales (Figure 4-4).
- The frequency of 1 in 100 year rainfall events is projected to increase significantly by the 2061-2080 period. A 1 in 100 year rainfall event in the observed 1981-2000 period (ca. 92 mm of rainfall) becomes approximately a 1 in 50 year event by 2061-2080.

Figure 4-2 - Projected changes in temperature in the North West based on the UKCP18 probabilistic projections for RCP8.5 (black with dashed uncertainty bands), RCP6.0 (red), RCP4.5 (purple), RCP2.6 (dark green). The observed temperatures are from the Central England Temperature record, which incorporates a station in Lancashire.

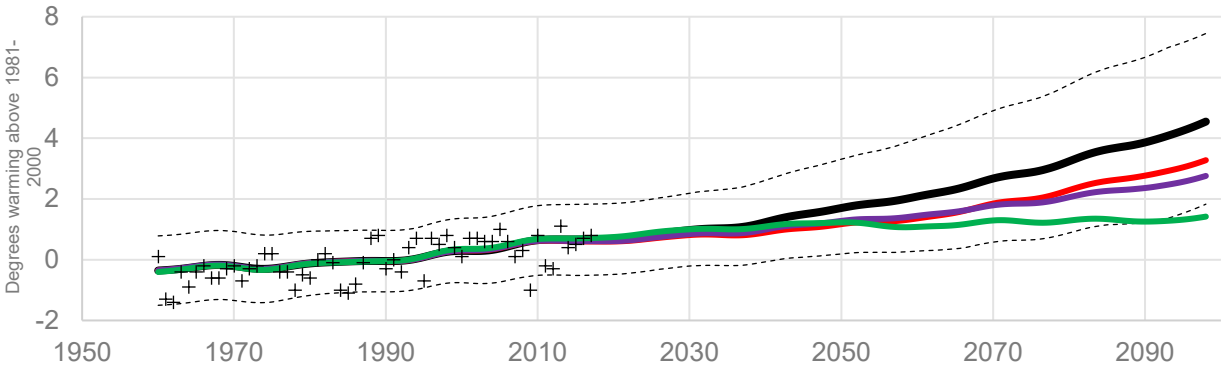


Figure 4-3 – Average summer maximum temperatures across Lancashire over different time periods The average temperature value for Lancashire is shown below the time period. (Median of Regional HADGEM3 set RCP8.5 projections)

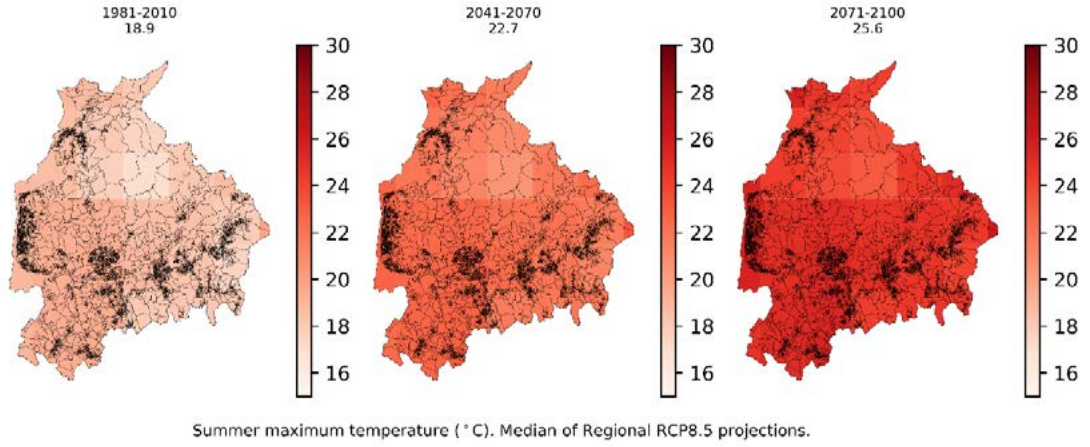
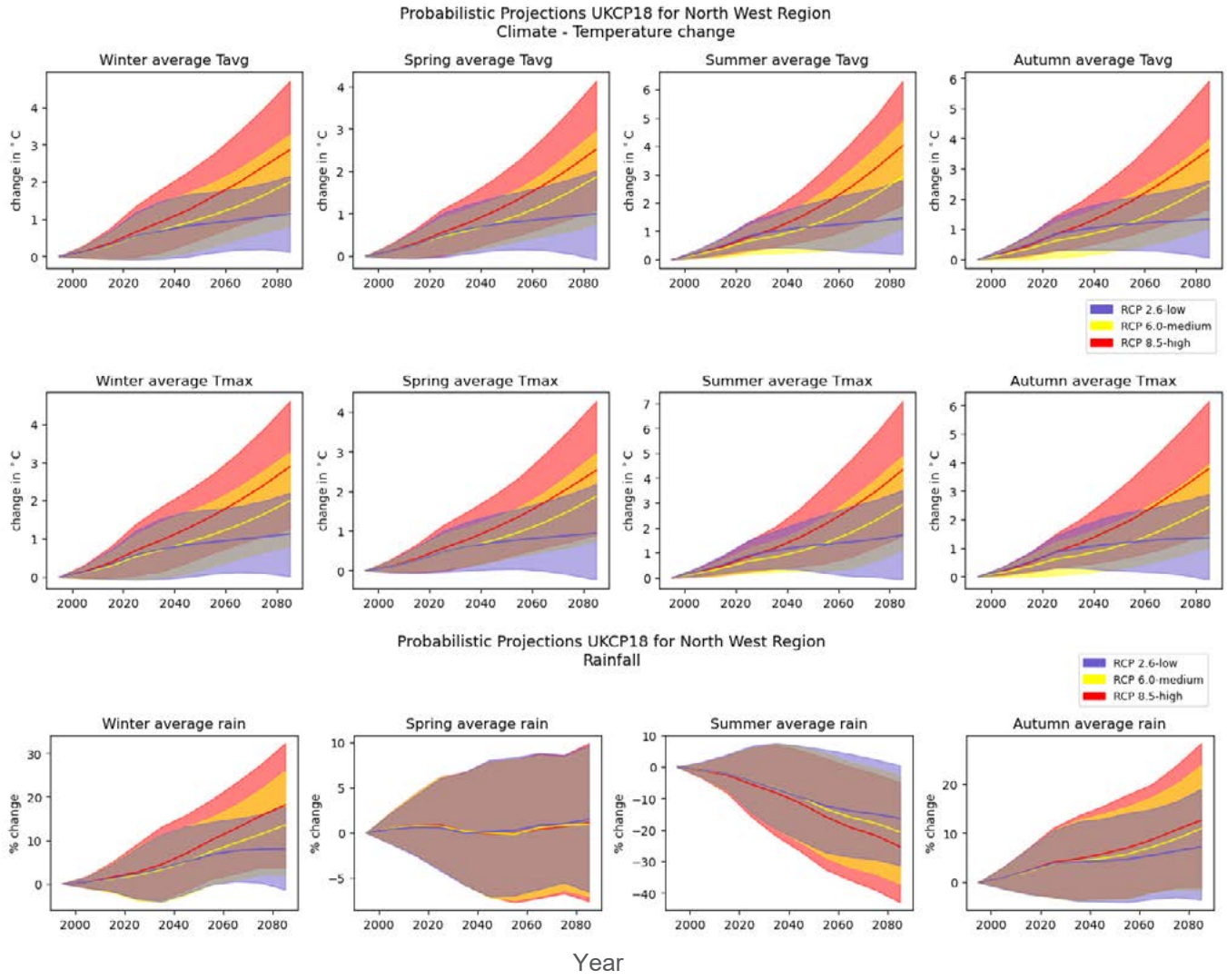


Figure 4-4 – Projected changes in seasonal temperature and precipitation for a range of scenarios for the North West of England



Notes: Change in seasonal mean and maximum temperatures and rainfall relative to 1981-2010, with the probabilistic RCP2.6, RCP6.0 and RCP8.5 ensembles. The plots show the 30-year mean change, plotted at the mid-point of the 30-year period. The shading shows the range between the 10th and 90th percentiles, and the solid line the median.

4.4. Biophysical impacts

Changes in climate have direct impacts on natural processes and cycles, which can have knock-on impacts across all sectors of the Lancashire economy. With warmer wetter winters, hotter drier summer and greater year-to-year variability, the hydrological cycle provides a range of key indicators of future climate change.

4.4.1. Floods and drought indicators

The flood risk indicator shows the likelihood of experiencing a flood greater than the reference period 10-year flood (annual probability of 10% in any single year). The Standardised Streamflow Index is a proxy for water resources drought frequency, which indicates periods of low river flow.

Both of these indicators were originally calculated at the Centre for Ecology and Hydrology (CEH) using the CEH Grid-to-Grid model, a national-scale rainfall-runoff and routing model that runs on a 1km grid across Great Britain. The average values for Lancashire have been sourced from Arnell et. al. 2021.

The implications are that there will be a 2.5 times increase in the likelihood of experiencing the current 10-year flood across the county. Research for the third national Climate Change Risk Assessment has indicated a

substantial increases in the total annual expected damages from flooding (around doubling loss and damage in England and Wales), which will not be fully addressed at the current rates of adaptation.

According to the drought indicator there may be twice as many streamflow drought periods by the end of the century. Low river flows impact on public water supply, supplies for industry and energy production, agriculture and the environment. Wetter winters are likely to provide increased resources but water companies will need to secure storage and transfer capacity to benefit from increase winter flows. Regional water resources plans will depend on improved water efficiency in households and businesses as well as reductions in leakage and the provision of new water supplies.

Figure 4-5 Change in hydrological indicators across Lancashire with high (RCP8.5) emissions, median of the global HADGEM3 projections. The maps show the 30-year mean indicators, rivers and urban area.

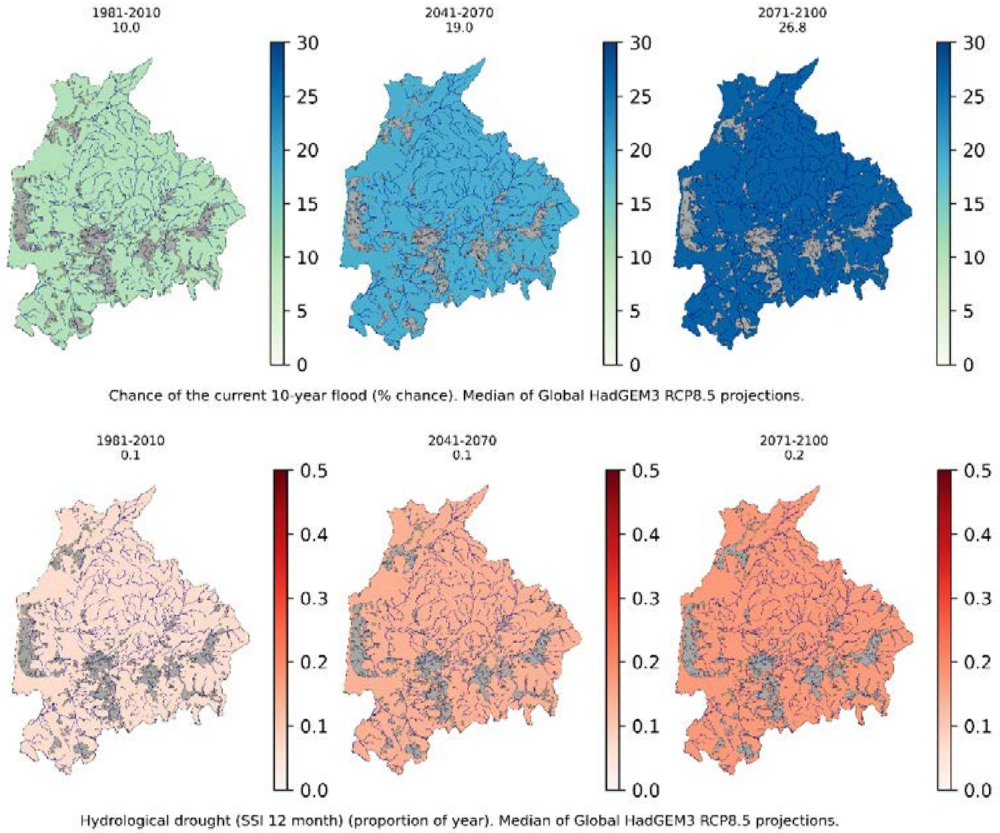


Figure notes: Indicators are from Kay et.al., 2020. Rivers - OS and Urban Area - CORINE. Contains OS and ONS data © Crown copyright and database right 2021.

4.4.2. Sea level rise

Lancashire has 173km of coastline and the Irish Sea is a major influence on the county and its economy. Heysham port provides key freight transport links to Belfast, Dublin and the Isle of Man along with facilities for servicing offshore renewable energy, gas and nuclear installations. Blackpool is the UK's most visited seaside resort and the focus of Lancashire's tourism sector. However, the county's coastal populations have pockets of poverty and extreme deprivation, associated with high levels of seasonal work at coastal attractions and distance from other employment opportunities[49].

Coastal areas and their assets are vulnerable to sea level rise and increased storminess, both of which may require hard or soft engineered protection and mitigation measures. Lancashire's coasts are covered by a Shoreline Management Plan (SMP) for the North West[50], which extends from Great Orme's Head in North Wales to the Scottish border in the Solway Firth. The SMP was formally adopted in 2016 and provides a large-scale assessment of the risks associated with coastal processes along with policies to reduce these risks

[49] Lancashire Interim Economic Review, 2021.
[50] Shoreline Management Plans – North West Coastal Group (mycoastline.org.uk)

through effective and sustainable management of flood and coastal erosion in the short, medium and long terms, i.e. between 0-20 years, 20-50 years and 50-100 years.

Without any active intervention over the long term, the SMP's presumption is that accelerated sea level rise will increase pressure on the coast as a whole and all current defences will eventually fail, causing the inundation of low-lying areas and rapid erosion of backing cliffs. However, this situation will eventually lead to the shoreline adjusting to a more naturally-functioning system where cliff erosion will provide material to feed local beaches. If beaches are allowed to move inland, instead of being caught between increased storm events and hard coastal defences, they will perform their natural function of providing coast protection.

Most of the Lancashire coast is encompassed in SMP Sub-cells 11b and 11c. From available information, particularly relating to the coast between Rossall Point and Wyre, the presumption is that hard defences will be maintained in order to protect coastal assets, a policy known as 'Hold the Line'.

Sea level rise in the UK is expected to increase up to 2100 and beyond under all UKCP18 RCP scenarios, with an increase in both the frequency and magnitude of coastal flooding events.

The UKCP18 marine climate projections indicate a median rise of around 0.65 m for Heysham under RCP8.5, but the upper estimate is just over 1 m and higher rates of sea level rise by 2100 cannot be ruled out. The most recent scientific evidence from the IPCC indicates higher rates of sea level rise, due to the melting of ice caps[51]. For this reason, coastal planners also consider a so-called H++ scenario of 1.9 m of sea level rise for sensitivity analysis. The main implications of sea level rise are an increase in the frequency of coastal flooding and potential loss of coastal habitats as these are 'squeezed' against hard defences with nowhere to migrate.

Figure 4-6 Regional mean sea level rise at Heysham in Lancashire under RCP8.5

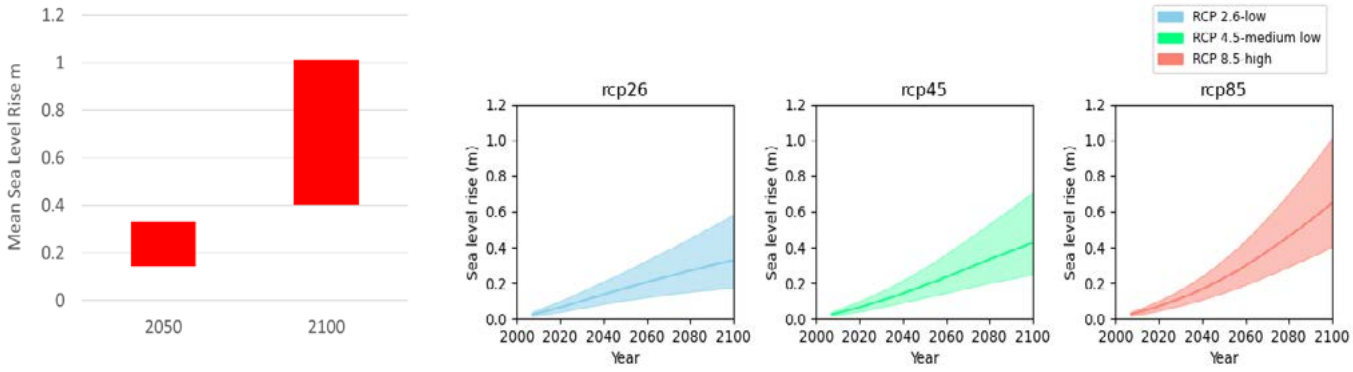


Figure Notes: Left – range of changes under RCP8.5 from the UKCP18 User Interface. Right -downloaded from CEDA archive: UKCP18 21st Century Time-mean Sea Level Projections around the UK for 2007-2100 (ceda.ac.uk)

4.5. Health and Wellbeing

Communities in Lancashire face increasing risks to health and well-being due to climate change, particularly due to extreme heat and extreme weather events, such as floods and windstorms. This section focuses specifically on the impacts of heatwaves and related indicators, which are relevant to all households, places of work and particularly the region's 10 main hospitals, 162 secondary schools and 5 prisons[52].

Lancashire has a lower life expectancy and lower "healthy life expectancy" than the national average, along with more serious self-harm incidents and more emergency hospital admissions. A higher proportion of the County's residents report their health as bad or very bad (6.3% of Lancastrians compared to the national average of 5.5%) and 21% have limiting long-term illnesses or disabilities compared to a national average of

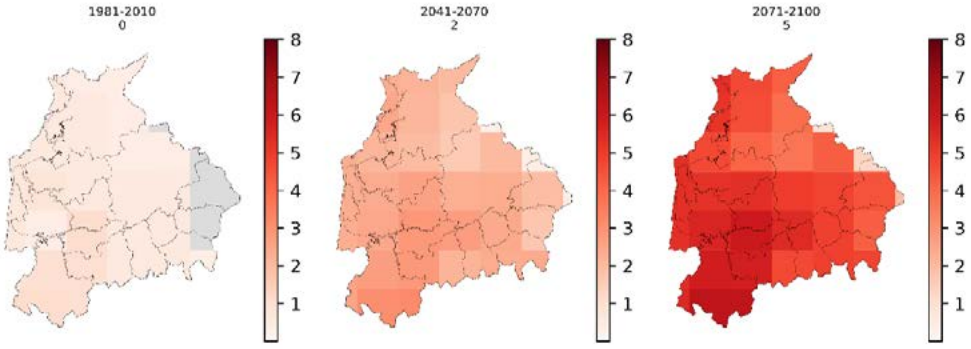
[51] The recent IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) reported that *"sea level continues to rise at an increasing rate. Extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (at least once per year) at many locations by 2050 in all RCP scenarios, especially in tropical regions (high confidence)"*
[51] Church et al. (2013). Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf
[52] Lancashire County Council (2021). Lancashire Insight. Available at: Lancashire Insight - Lancashire County Council [Accessed: 11/05/2021].

17%. Communities in areas of higher deprivation may have poorer access to services, particularly in rural areas. Increased sensitivity and poor coping capacity makes these communities more vulnerable to extremes of heat or cold as a result of climate change.

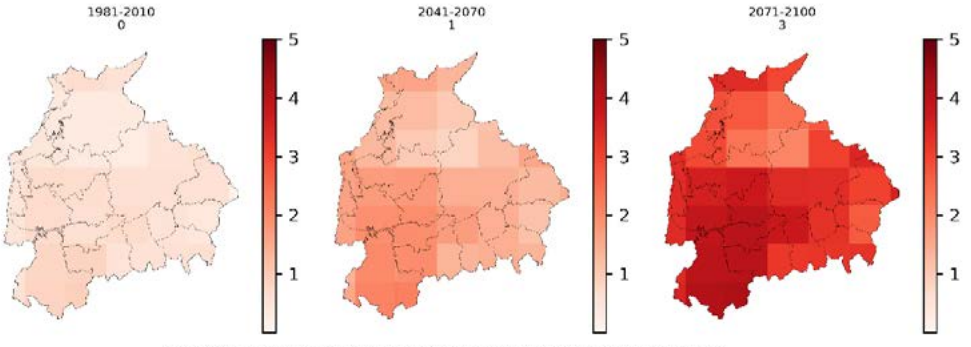
The figures below show the impact climate change could have on heatwaves, heat-health alerts, and cold weather alerts in Lancashire. Climate change is projected to increase the frequency and length of heatwaves and heat-health alerts with current thresholds of an average of 25°C and/or day-time 30°C / night-time 15°C temperatures. Figure 4-7 shows that after 2071, West Lancashire, the Borough of Chorley, South Ribble, the City of Preston, and Blackpool could experience up to 5 heatwaves and 8 heat-health alerts a year (central estimate), with an average of 3 and 5 across Lancashire, respectively. Summer maximum temperatures of 25-30°C in urban areas could become a new normal towards the end of the century, with annual average temperatures increasing by 4°C across Lancashire.

Consequently, cold weather conditions become less frequent, and the number of cold weather alerts falls to 1 event a year. Extreme heat events are likely to have greater impacts over a longer duration, in particular where they affect food and water supplies, decrease productivity, and increase pressures on vulnerable people through heat stress and health complications (particularly for the elderly and immunocompromised).

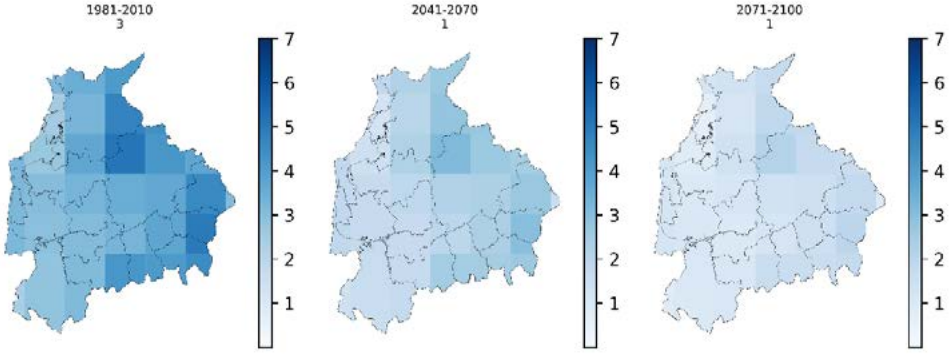
Figure 4-7 –Indicators of hot and cold temperature extremes across Lancashire across different time periods, based on the median of probabilistic RCP8.5 projections. The average value for Lancashire is shown below the time period.



Amber heat-health alerts (Events/year). Median of Probabilistic RCP8.5 projections.



Met Office heatwaves (Events/year). Median of Probabilistic RCP8.5 projections.



Amber cold weather alerts (events/year). Median of Probabilistic RCP8.5 projections.

Top row: Met Office heatwaves. Middle row: Amber-heat health alerts. Bottom row: Amber cold weather alerts. Grey shading represents 0 events.

Figure notes: The Met Office defines a '**heatwave**' as a period when maximum daily temperatures exceed region-specific thresholds for at least three consecutive days. For the North West region, this threshold is 25°C.

The **heat-health alert** ("Amber alert") indicator is based on the heat-health alert temperature threshold (Day 30°C/Night 15°C), which initiates NHS England heatwave plans. The Heatwave Plan for England[53] specifies emergency measures that are implemented in health and social care services on receipt of a heat-health alert warning. The heat-health watch alert system has five levels, currently operates from 1 June to 15 September, and is based on temperature forecasts from the Met Office. Level 2 (Yellow) is triggered when a heatwave is forecast, and Level 3 (Amber) when a heatwave begins. Level 4 represents a national emergency.

Cold weather alerts ("Amber alerts") identify cold weather emergencies for health and social care services to help manage pressures on the health system and reduce public mortality. The Cold Weather Plan for England[54] involves strategic planning and seasonal preparedness, communications, and a similar 5-level alert system as for hot weather. An amber 'cold weather' alert (Level 3) occurs when average temperatures fall below 2°C for at least two consecutive days.

These three indicators (heatwaves, heat-health alert, cold weather alerts) are all based on the occurrence of temperature extremes beyond a threshold, used to initiate an alert. In practice, alerts are based not just on exceedances at a location but also on the spatial extent of the event. The heat-health and cold weather alerts are also issued at a regional level if the threshold is exceeded somewhere in that region, or a neighbouring one.

4.6. Energy Use

Climate change will impact on the energy used for cooling and heating demand, for transport and in a range of utility and industrial sectors. This section addresses cooling and heating demand. Transport is discussed in Section 4.7.

Electricity North West is the principal electricity supplier in Lancashire and Cadent Gas is responsible for the gas network. In 2018, average yearly energy consumption of a Lancashire household stood at 3,402 kWh. 68% of all households use gas for central heating, 10% use electricity, 10% use oil and the remaining 12% do not have central heating installed. The average price of energy in Lancashire is £11.05 per kWh[55].

Road transport and domestic gas are the two largest contributors to energy use in Lancashire, responsible for 28% and 22% respectively[56].

The graphs below show the projected changes to the number of days where buildings and homes may need to be heated or cooled to provide a comfortable environment for people. The analysis demonstrates that climate change is projected to decrease days requiring heating across Lancashire and by the 2050s these could be 30–40% lower than at present. Over the same time period there will be a more than tenfold increase in the days where cooling is required.

Figure 4-8 Energy indicators for the North West administrative region. The plots show the 30-year mean change, plotted at the mid-point of the 30-year period with the probabilistic RCP2.6, RCP6.0 and RCP8.5 scenarios. The shading shows the range between the 10th and 90th percentiles, and the solid line the median.

[53] Heatwave Plan for England (publishing.service.gov.uk)
[54] The Cold Weather Plan for England: Protecting health and reducing harm from cold weather (publishing.service.gov.uk)
[55] Switch Plan (2021). Electricity & Gas in Lancashire in 2021. Available at: https://www.switch-plan.co.uk/energy/lancashire/. [Accessed: 11/05/2021].
[56] Lancashire County Council (2021). Lancashire Insight. Available at: Lancashire Insight - Lancashire County Council [Accessed: 11/05/2021].

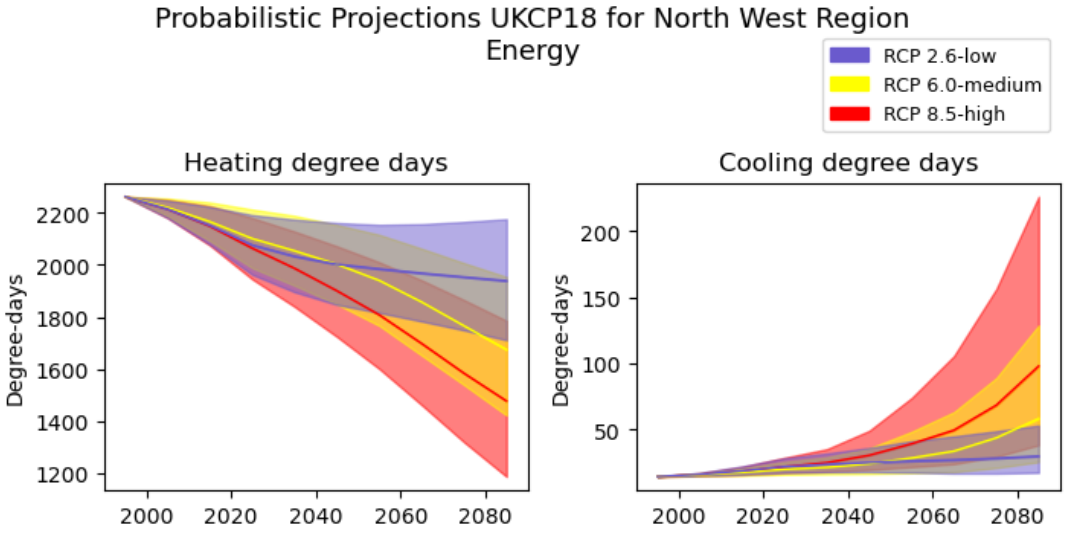
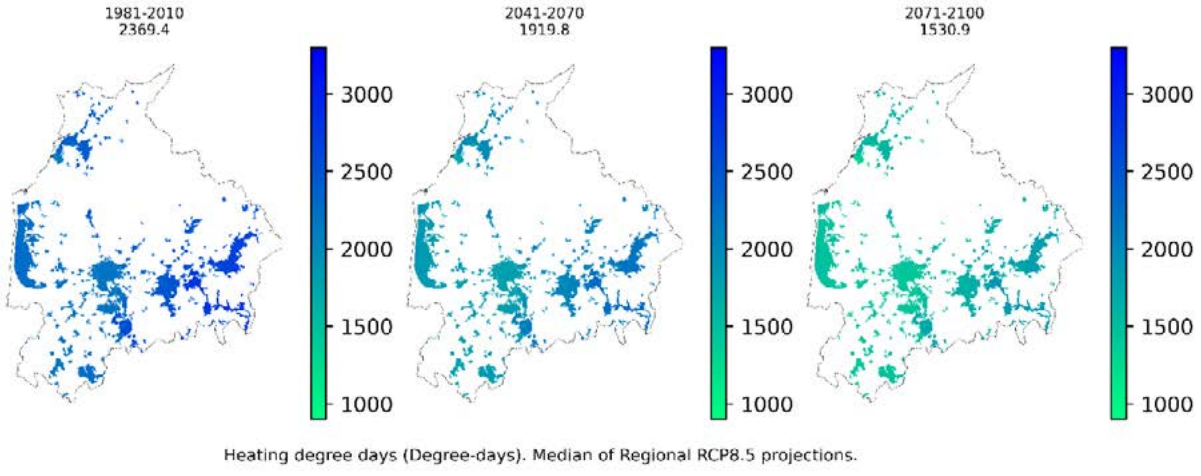


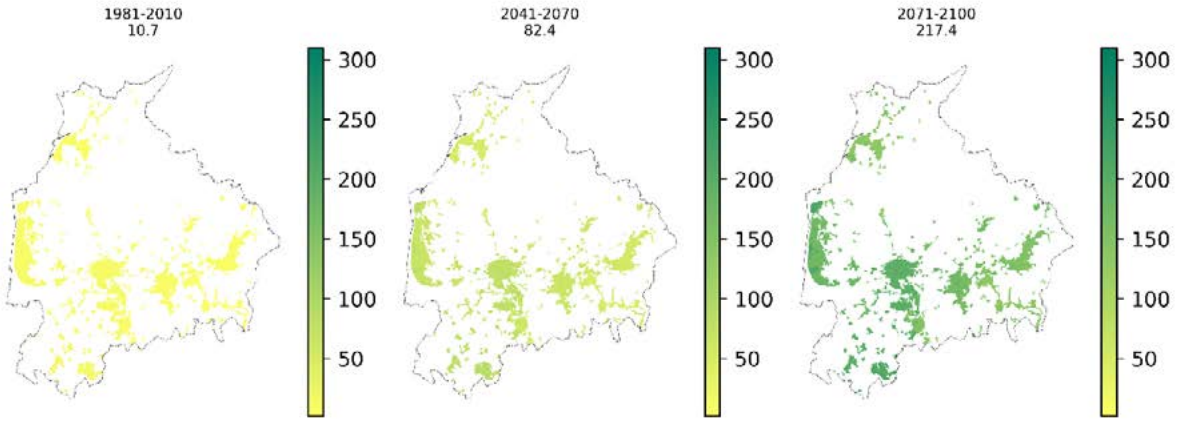
Figure notes: Heating and cooling degree days (HDD/CDD) are proxies for heating and cooling energy demand, based on thresholds used in building management. HDD/CDD measure of how much (in degrees), and for how long, outside air temperature was higher or lower than a specific threshold. These metrics quantify the amount of heating/cooling buildings need over a certain period to provide a comfortable environment for people. One HDD means that the temperature conditions outside the building were equivalent to being below a defined threshold comfort temperature inside the building by one degree for one day. Thus, heat has to be provided inside the building to maintain thermal comfort. Both indicators are calculated using thresholds of 15.5°C and 22°C for heating and cooling degree days respectively.

The impact on household and workplace energy bills is complex due to the relative price differences between the costs of gas and oil used for heating and higher unit cost electricity, which would be needed for cooling. Warmer winters may have a positive impact on fuel poverty, but the need for cooling and higher costs or lower carbon energy for heating may cancel out the positive impacts for household bills.

Increased cooling demand and decreased heating demand will also affect the energy mix and technologies required across Lancashire; for example, air conditioning powered by electricity is likely to increase, while gas heating is likely to decrease. In parallel, energy sources will transition to low carbon, likely increasing demand on electricity. Climate change will require the generation of electricity from renewable sources such as wind and solar; in turn, it is important that proposed energy infrastructure considers the impacts of climate change on generation capacity and downtime due to weather extremes. These issues are part of the overall consideration given to climate change through the Representation Concentration pathways and the options within the Lancashire Net Zero study (see 4.2.1).

Figure 4-9 The spatial distribution of energy indicators across Lancashire Residential Area.





Cooling degree days (Degree-days). Median of Regional RCP8.5 projections.

Figure notes:

Top row: Heating degree days. Bottom row: Cooling degree days. Median of Regional HADGEM3 set RCP8.5 projections (from Arnell et al. 2020). Contains OS and ONS data © Crown copyright and database right 2021.

4.7. Transport

Climate change will impact Lancashire's transport systems – including through disruption from extreme weather events, and changing demand for transport (for example, more people may choose to drive if rainfall increases). This section focuses on the impact of extreme weather on transport.

Lancashire's road network spans 7,046 km, with 6,159 km of minor roads and 887 km of motorways and A roads. Main motorways include: the M6, traveling north to south; the M65, connecting the west of the county; and the M55, connecting the east[57]. Highways England operates, maintains and improves England's motorways and major A roads and the local authorities are responsible for maintaining the local critical road network including managing cold weather gritting, asset deterioration, resurfacing and drainage. After extreme events authorities may apply for emergency funding from the Department of Transport to fund repairs.

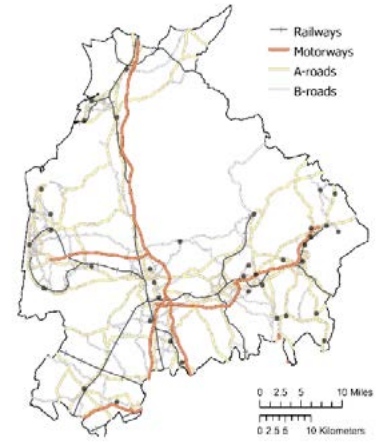
There are 52 train stations within Lancashire, major stations in the county include Lancaster, Blackpool North, Preston and Blackburn. Network Rail is responsible for most existing rail assets. HS2 plans to connect Preston to Birmingham and London, aiming to increase rail activity for the county[58].

Heysham port provides daily sailings to the Isle of Man and Ireland, catering for both passengers and roll-on roll-off freight traffic. Blackpool Airport only provides private flights and flights for the offshore energy industry. The Tramway linking Blackpool and Wyre had 4.8 million passengers in 2019/20. A summary of passenger numbers for different modes of transport is shown in the table below.

	Bus and Tram	Train	Blackpool-Wyre Tramway	Ferry
2019/2020 Passengers	40 million	17 million	4.8 million	268,000

[57] Lancashire County Council (2021). Lancashire Insight. Available at: Lancashire Insight - Lancashire County Council [Accessed: 11/05/2021].
[58]Lancashire County Council (2021). Lancashire Insight. Available at: Lancashire Insight - Lancashire County Council [Accessed: 11/05/2021].

Figure 4-10 Motorways, A-roads, B-roads, railways in Lancashire.



Roads and railways (OS Strategi®). Lancashire

Source: Metro Dynamics analysis of Bing aerial, NASA, Ordnance Survey. Elevations have been accentuated for clarity.

Major roads and railways in Lancashire are shown in the figures above. Lancashire's physical geography has meant that transport infrastructure has become more aligned with the North-South axis, but the county's centres of population are aligned from east to west, from Blackpool to Colne. Public transport options in rural communities tend to be poor, which leaves residents highly car-dependent. This has consequences for the environment and efforts to reach Net Zero[59]. The county's economic geography is constrained due to poor transport connections on the east/west axis, which means that links with economic centres in Yorkshire are weak.

Climate change affects transport infrastructure and its operational performance, and this assessment has focused on roads and rail. Road surfaces can melt when they warm above 50°C, which often occurs when air temperature exceeds 33°C. Over time, this reduces the longevity of roads, which require increased maintenance to fix potholes and other structural problems. Road surface melting/buckling, even at lower temperatures, is a known problem within local authorities and has already led to changes in the specification of the asphalt used for resurfacing. The number of rail track buckling incidents increases when daily maximum temperatures exceed 26°C, and incidents relating to rail power supplies and warning systems increase above 30°C. When rail track temperatures are higher than critical values, specific operational measures (e.g. speed restrictions) are introduced. The figures below show climate indicators relevant to transport systems across Lancashire over different time periods. The first row shows the number of days at risk of roads melting (above 33°C), the second row shows the number of days where rail tracks are at risk of buckling (above 26°C), and the third row shows the number of days where increased rail power supplies and warning systems are at increased risk (above 30°C).

[59] Rural Services Network quoted in 'Taking Stock: An audit of Lancashire's economy in 2021' (Lancashire Independent Economic Review)

Figure 4-11 Climate indicators relevant for transport systems across Lancashire over different time periods based on median of Regional RCP8.5 projections.

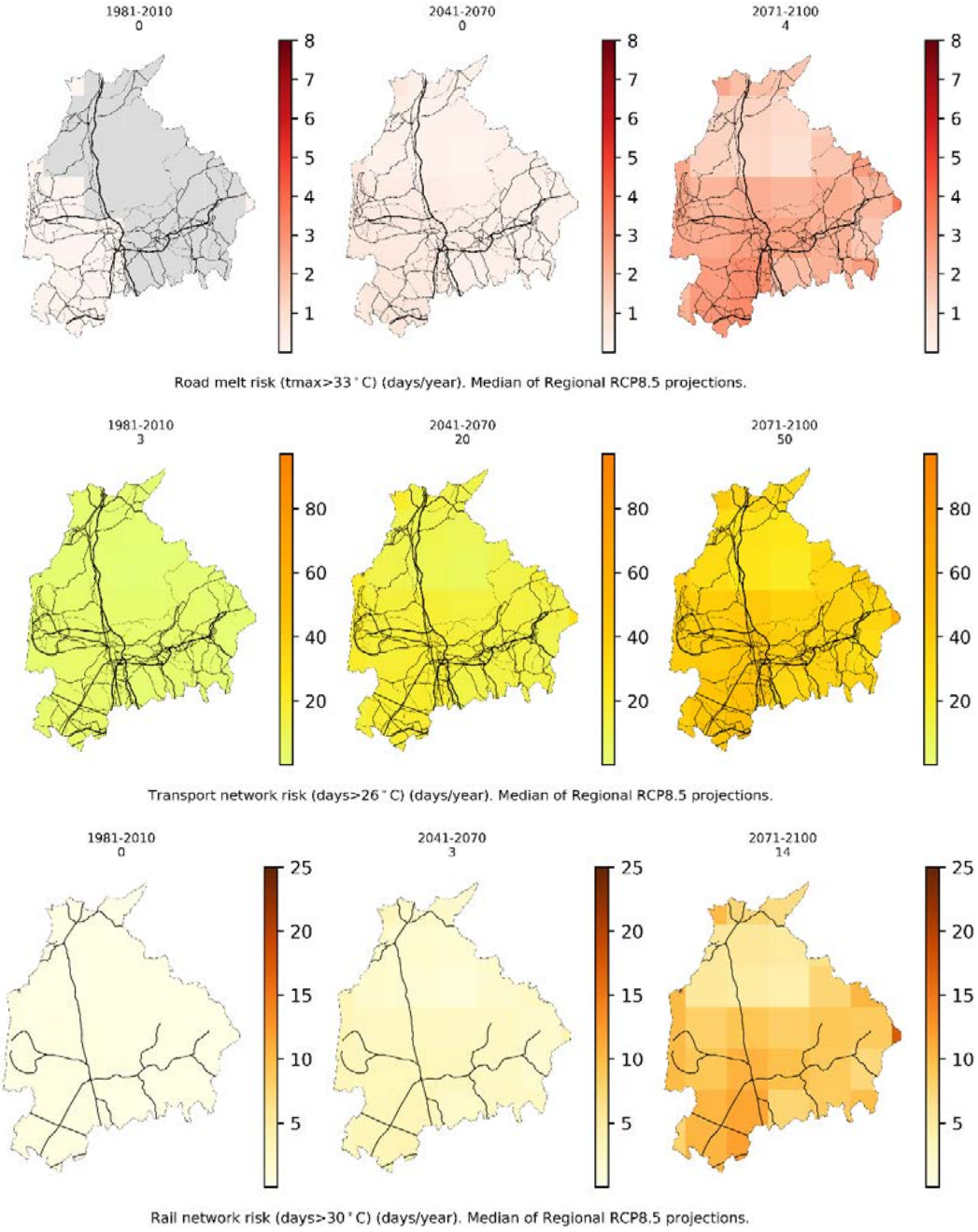


Figure notes: Maps show A and B-roads, motorways and rail tracks. The bottom row shows rail tracks only. Top row: Road melt risk (30-year mean number of days with maximum temperature higher than 33°C.) Middle row: Rail track buckling risk (30-year mean number of days with maximum temperature higher than 26°C.) Bottom row: Rail power supplies and warning systems risk (30-year mean number of days with maximum temperature higher than 30°C). Grey colour represents 0 events.

In addition to the above risks due to heat, extreme weather events create additional risks. Rail operating companies must meet performance and punctuality standards, but these standards are slightly relaxed on days with 'bad' weather. Network Rail's operating standards define thresholds for adverse or extreme wind, rain, temperature, and snow. 'Adverse weather days' are counted as the number of days per year when one or more of the adverse thresholds are exceeded. The graphs below demonstrate the increasing number of 'adverse

weather' days for rail systems in the North West of England, alongside the increasing days with road melt risk, rail track buckling risk, and rail power supplies and warning systems risk.

Figure 4-12 Transport indicators for the North West administrative region

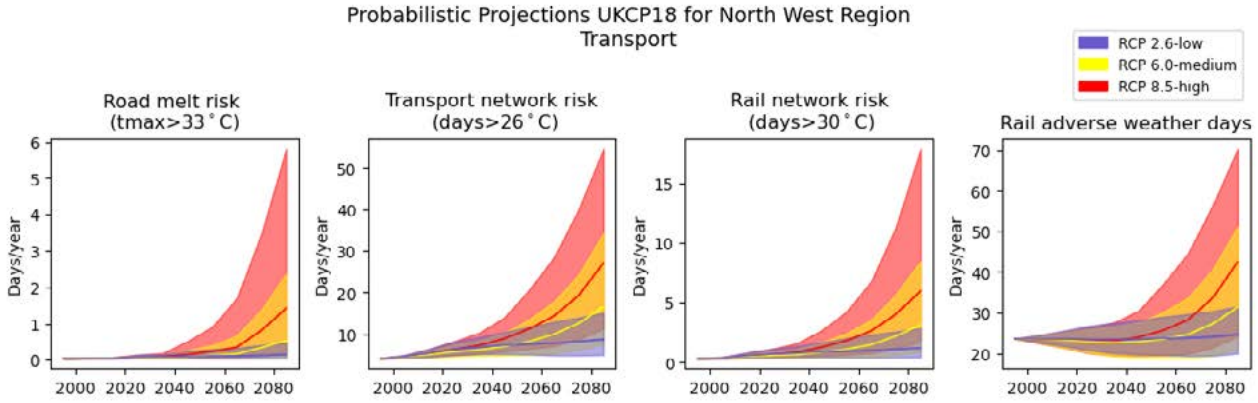


Figure notes: The diagrams show the 30-year mean change, plotted at the mid-point of the 30-year period with the probabilistic RCP2.6, RCP6.0 and RCP8.5 ensembles. The shading shows the range between the 10th and 90th percentiles, and the solid line the median (Figure S7 Page 14. Supplementary Material. Arnell et. al 2020)

4.8. Agriculture and Forestry

Agriculture represents the largest single land use in Lancashire. With a wide range of farming types and areas of high grade agricultural land, the county makes a major contribution to the nation's food supply.

Figure 4-13 Lancashire Land Cover and agricultural land grades

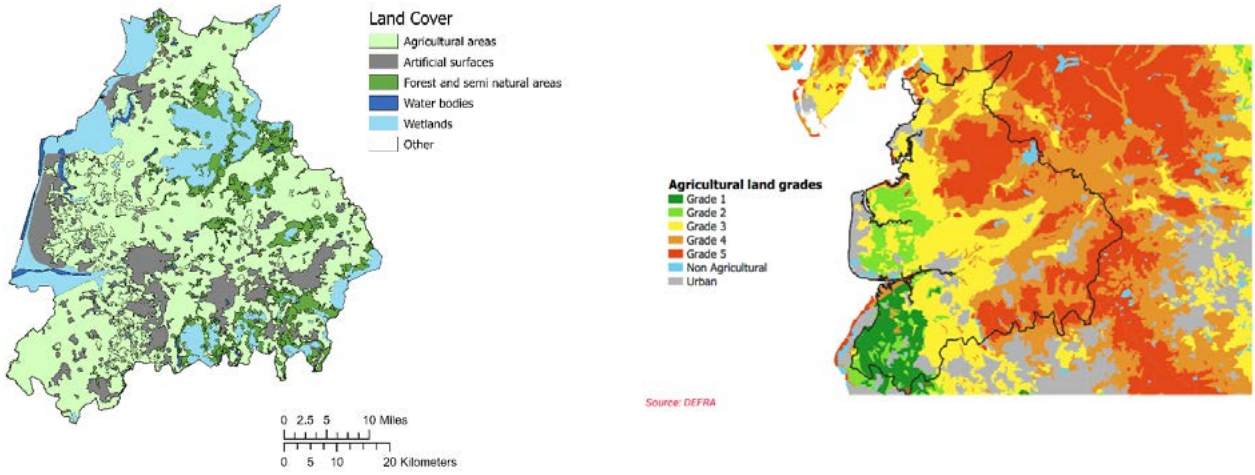


Figure Notes: The CORINE Land Cover (CLC) 2018 and agricultural land grades from the IER interim report, 2021.

The coastal plains are used for intensive horticulture and general cropping, the lowland areas are occupied with dairying, whereas cattle and sheep rearing are a large part of the upland rural economy and important to cultural heritage values. The most productive land (grades 1 and 2), capable of growing a wide variety of agricultural crops, is concentrated in Fylde and West Lancashire. These areas support the largest concentration of top-quality farmland in the west of Britain. Other parts of the county are best suited for grass crops and rough grazing.

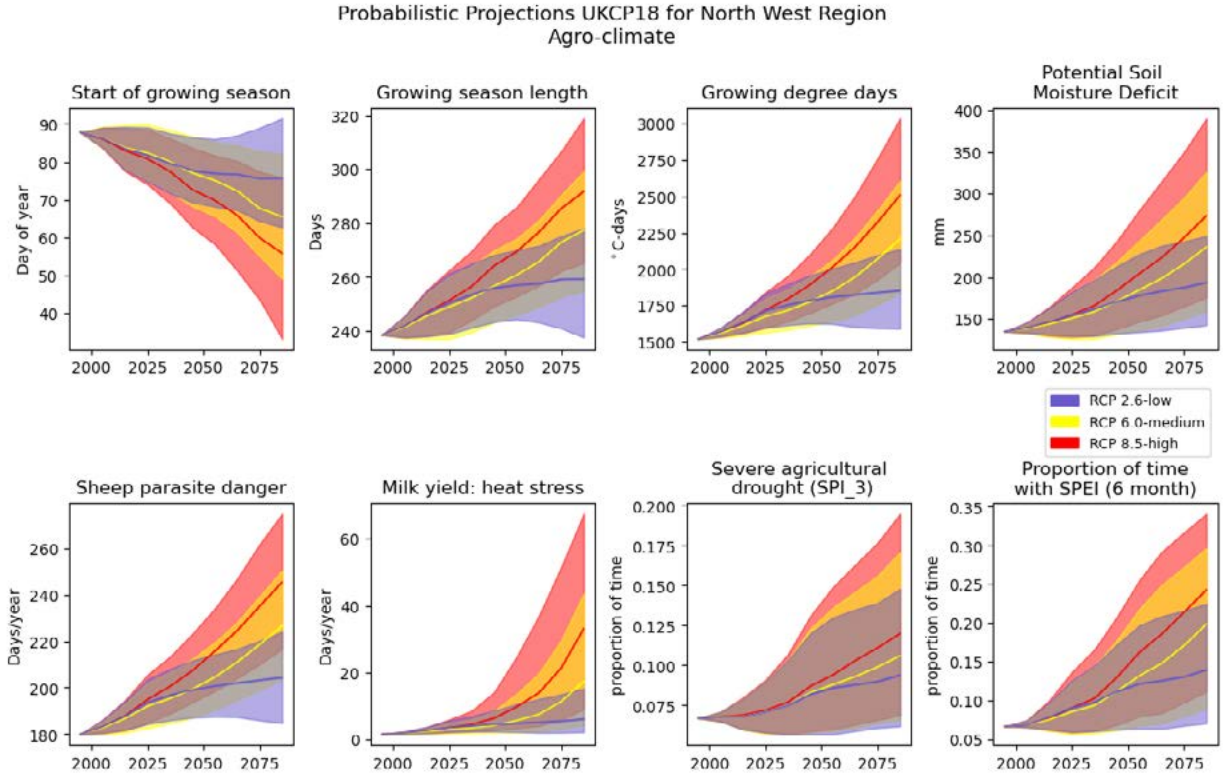
The thermal growing season is an important agricultural resource. It starts when average temperature has been above 5.6°C for five days and finishes when temperatures have fallen below 5.6°C for five days. Growing degree days (GDD) could determine plant development in the absence of other constraints, such as water or nutrient availability. This indicator influences which annual crops could feasibly be planted and is also important

for productivity of perennial crops, such as grassland. The start of the growing season and growing season length are important indicators of climate change.

Other indicators describe agricultural hazards including agricultural drought, animal parasites and animal heat stress. Agricultural drought was characterised by the Standardised Precipitation-Evaporation Index (SPEI-6), which was calculated from precipitation and potential evaporation accumulated over 6 months and the Standardised Precipitation Index (SPI) based on precipitation totals accumulated over 3 months (SPI-3).

Figure 4-14 shows the significant changes in most of the agro-climate indicators across Lancashire. These changes are smaller with the lowest RCP2.6 emissions, but the risk still occurs. The number of days with temperatures supporting sheep parasites increases by up to 30 days by the 2050s. The number of days causing heat stress for dairy cattle also increase.

Figure 4-14 Agricultural indicators of climate resource (top row) and hazard (bottom row)



From Fig 4,5 Arnell & Freeman, 2021b (Agro-climate paper)

Figure Notes: Probabilistic projections, RCP2.6, RCP6.0 and RCP8.5. The 30-year mean values are plotted at the central year of the 30-year period. The plots show the median plus the 10th to 90th percentile ranges (low to hight). The shading shows the range across the ensemble members and the solid line the median.

Heat stress leading to reduced milk yield in dairy cattle is the number of days that the Thermal Heat Index (THI) is higher than 70 (equivalent to an average temperature of around 21°C with a typical relative humidity of 75%). With increase in the number of days where THI is above 70, milk yield tends to fall.

Parasite outbreaks in sheep is correlated with the number of days with average temperature above 9°C. This is an indicator of the potential number of life cycles of a gastro-intestinal parasite (*Haemonchus contortus*), which causes ill-health in sheep.

Potential Soil Moisture Deficit (PSMD) is the maximum value during the year of the accumulated difference between precipitation and potential evaporation. It is a measure of crop demand for water and hence the potential need for supplementary irrigation. The climatic suitability of land for agriculture is often based on PSMD. Forestry has not been assessed in detail here but is sensitive to GDD, soil moisture, windstorm and the prevalence of forest pests and diseases that are influenced by climate change.

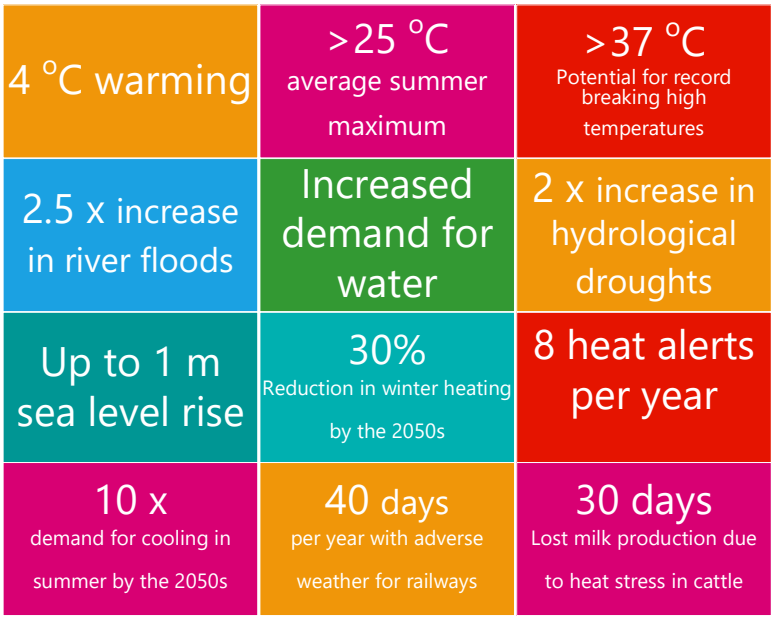
The potential soil moisture deficit and drought frequency (expressed as the proportion of time in drought) increases very substantially across Lancashire, particularly in West Lancashire (arable land). By the 2080s, severe drought conditions could occur around 30% of the time compared with 6.7% now.

With the highest emissions, the start of the growing season is brought forward by between 10 and 40 days by the 2080s, a change of around 1 to 4 days per decade. It would also be 40-70 days longer by the 2080s. Growing degree days could double by the 2080s. The rate of change is higher for Ribble Valley, Pendle, Lancaster, Blackburn with Darwen and Hyndburn.

The full list of agriculture indicators and additional maps are presented in Appendix A.

4.8.1. Headline findings on climate change for Lancashire

The headline messages for Lancashire are:



- **Climate:** For RCP8.5, Lancashire's climate is projected to significantly change with a 2-3°C temperature increase in winter, a 3-5.5°C increase in summer, a 20-30% increase in winter rainfall and a 20-40% decrease in summer rainfall. Summer average maximum temperatures of 25-30°C in urban areas could become a new normal towards the end of the century, with annual average temperatures increasing by 4°C across the region. Maximum summer temperatures could exceed 37°C in parts of Lancashire[60].
- **Floods:** There is likely to be significant increase in rainfall intensity, with a two-fold increase in the frequency of very heavy rainfall[61], leading to more frequent river flooding across the county. Without enhanced adaptation this will lead to an increase in damage and losses due to flooding. Flooding and coastal change risks to communities, built environment and infrastructure are regarded as top priority for national and regional adaptation planning.
- **Drought:** There could be twice as many hydrological droughts (duration of low river flows) as at present by the end of the century, which has potential impacts on public water supply and the environment; water companies are preparing for more extreme droughts but rising water scarcity is likely to prompt further action to promote water efficiency and maintain supplies.
- **Sea level rise:** Projected rates of sea level rise are higher than in previous assessments and could rise by 1 metre under the RCP8.5 scenario. Even under lower emissions, there will be some increase in sea level rise. This means it is necessary to pursue both increased resilience to changing coastal risks and reduced emissions to contribute to UK and global efforts to meet the Paris Agreement. Consideration also needs to be given to the long term shoreline management measures deployed to protect assets along the County's coastline.
- **Health and well-being:** Climate change is projected to increase the frequency of heatwaves and decrease cold weather events. West Lancashire, the Borough of Chorley, South Ribble, the City of Preston, and Blackpool could experience up to 5 heatwaves and 8 heat-health alerts a year, with an average of 3 and 5 across Lancashire respectively. Consequently, cold weather conditions become less frequent and the number of cold weather alerts falls to 1 event a year. This has implications for health and social care, particularly for the elderly and those living in poor housing conditions or with limited access to greenspace.

[60] Potential maximum temperature based on the simplified 4°C analysis in the Met Office/BBC tool What will climate change look like in your area? - BBC News
[61] Based on analysis of extreme 100 year rainfall by Atkins using the Flood Estimation Handbook and UKCP18 data

- **Energy use:** Climate change is projected to decrease days requiring heating across Lancashire; by the 2050s, these could be 30–40% lower than at present. Over the same time period there will be a more than tenfold increase in the days where cooling is required. While warmer winters may relieve some pressure on fuel poverty, the need for active cooling in summer will increase energy costs, particularly as electricity used for cooling has higher unit costs than current gas heating arrangements.
- **Transport:** Climate change is projected to increase risks for transport systems due to high temperatures and extreme weather events. Currently, the incidents of melting roads in Lancashire are rare but, after 2050, they could occur up to 4 times a year in West Lancashire, Chorley, South Ribble and City of Preston. The North West Transport network, including roads and rail tracks, could be at risk of 25-50 days a year of power supply failures and 17 days each year of warning systems failures. The number of rail adverse weather days could increase from current 20 to as high as 70 each year.
- **Agriculture:** an earlier spring, longer growing season and increase in growing degree days is likely to benefit pastures but more agricultural droughts and higher soil moisture deficit may adversely affect arable land. Higher temperatures are likely to impact on livestock, pests and diseases as well as milk production. Farmers and land managers will need to adapt to respond to both the opportunities and threats of future climate change.

5. How prepared is Lancashire for climate change?

This section considers how prepared Lancashire is for future climate change. It is based on a review of the available literature, our knowledge of climate adaptation and resilience in key sectors and interviews with officers from Lancashire Council, Blackpool Council and Blackburn with Darwen Council. The climate indicators in Section 4 describe the magnitude of future changes and the likelihood of exceeding relevant thresholds, but the risks and opportunities for Lancashire depend on the adaptive capacity of institutions, existing plans and strategies (that include adaptation actions) and further action to increase climate resilience that can be delivered through the economic strategy. The first two aspects are briefly considered below, followed by some good practice examples of climate adaptation in Section 6. In addition, some high level recommendations are provided in Section 7 on the integration of climate resilience into policies, strategies and plans to deliver "Climate Resilient Lancashire."

5.1. Adaptive Capacity

Adaptative Capacity, with respect to climate change resilience, is defined as the *'ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences [of climate change]'*[62]. As part of this resilience study, Atkins has interviewed a range of local authority Officers to gain a 'snapshot' understanding of the region's adaptive capacity. The interviewees represent a range of sectors within the authorities, covering but not limited to Highways, Building Design, Public Health and Social Care, to help understand the breadth of capacity. Results are presented qualitatively and have been used to inform an assessment of adaptative capacity across five key themes: Awareness, Agency, Collaboration, Operations and Learning.

5.1.1. High Level Assessment

Table 5-1 presents a high-level assessment of the Adaptative Capacity of Lancashire based on the interviewee responses to a range of targeted questions and broader discussions addressed during the interviews. Particularly, it reflects the interviewees' responses to the questions presented in in Figure 5-1 and prompts to provide examples of good practice.

In order to provide some context, we would only expect world leading and well-funded institutions to have the highest levels of adaptive capacity, followed by those whose primary business is managing climate risk, such as the insurance sector or leading major water utilities.

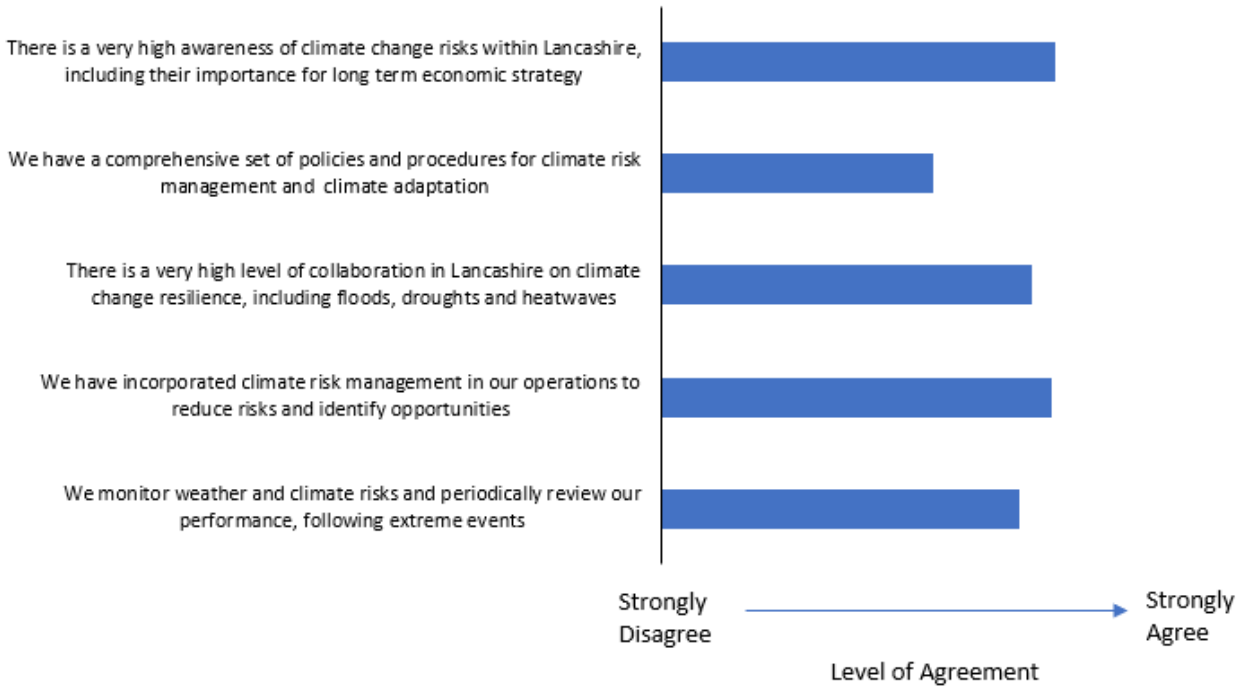
The criteria for this assessment are presented in Appendix B.

Table 5-1 - Adaptative Capacity Assessment for Lancashire County Council

Adaptive Capacity	Very Low	Low	Medium	High	Very High
Awareness					
Agency					
Collaboration					
Operations					
Learning					

[62] BSI_EN ISO 14090:2019 with definition adapted from IPCC, 2014

Figure 5-1 - Agreement with a set of 'preparedness' statements from the interviewees



The local authorities interviewed in Lancashire have scored medium in the areas of Awareness, Collaboration and Operations. This reflects the broad awareness of the challenges posed by climate change and how they affect each organisation, as well as some good examples of collaboration and operational plans.

Although a Climate Emergency has been declared across the local authorities, the Agency score is limited by the need for this emergency to be communicated more successfully and to take further steps to implement actions on updated policies and procedures. In addition, in some cases discussion and analysis of the Climate Emergency is solely focused on Net Zero without considering climate resilience.

Some authorities are in the process of updating their Climate Action Plans, including some action on managing climate risks, as well as introducing a climate change section to all policy papers before they are submitted to Council Committees.

There is some reflection on operational performance following extreme events, these reviews are described as quite *ad-hoc* and should be developed to follow established review processes to improve the learning metric.

Table 5-2 presents an overview of the strengths and areas for development within each theme. These strengths and development areas are reflective of the assessment presented above and comments from the interviewees.

Figure 5-2 represents the interviewees' perceived risks of a range of hazards from climate change. River and surface water flooding held the greatest perceived risk across the interviews. This includes surface water flooding in areas away from major rivers, as well as flooding on the River Ribble and other large rivers. This reflects the significant, visible and immediate impacts of these events on Lancashire, which are felt across multiple sectors. The remaining risks scored broadly quite similarly, which reflects an awareness of issues across sectors.

Recommendation: Lancashire's local authorities need to work in partnership with other organisations to deliver climate resilience, including the NHS, the Environment Agency, emergency services and housing organisations amongst others. A broader stock-take is required to understand current levels of adaptive capacity and preparedness for future climate change.

Some information on adaptation planning by different organizations is included in Section 5.2.

Table 5-2 - Overview of the strengths and areas for improvement by adaptive capacity theme

Key theme	Strengths	Areas for Improvement
Awareness	• Good understanding of sector specific hazards • A developing understanding of the interconnections between sectors	• Although a Climate Emergency has been declared there is the need for additional communication about what this means and to work through the impact on policies and procedures.
Agency	• Good knowledge of professional standards that include climate change allowances, for example in Environment Agency or CIBSE guidance. • Relevant guidance is used to drive policy. In some cases, this stems directly from national guidance. • Some authorities have developed climate change design guidelines for new housing developments.	• Policy and procedures are generally reactive rather than proactive. • Funding is seen as a cross-sector challenge
Collaboration	• Some good examples of multi-disciplinary collaboration • Examples of joint working between LCC, local authorities, EA and other stakeholders.	• There can be grey areas around ownership of schemes / asset maintenance • Desire for a more holistic approach with a dedicated climate change group working across disciplines.
Operations	• Reference to plans that can be utilised during response to extreme events. Several plans in place with the ability to draw on resources where required. • Climate change is considered through a variety of zero / low carbon technology.	• Currently there is a reliance on data provided by the Met Office and other government departments. This could be improved to incorporate more bespoke weather services for Lancashire.
Learning	• There are some elements of review across the interviewed sectors which can inform decision making	• Reviews are often driven by extreme events or undertaken on an *ad-hoc* basis. There is scope for additional reviews following established review processes to allow greater influence on policy and decision making

Source: Based on interviews with staff from 3 authorities.

Figure 5-2 - Perceived risks from climate change

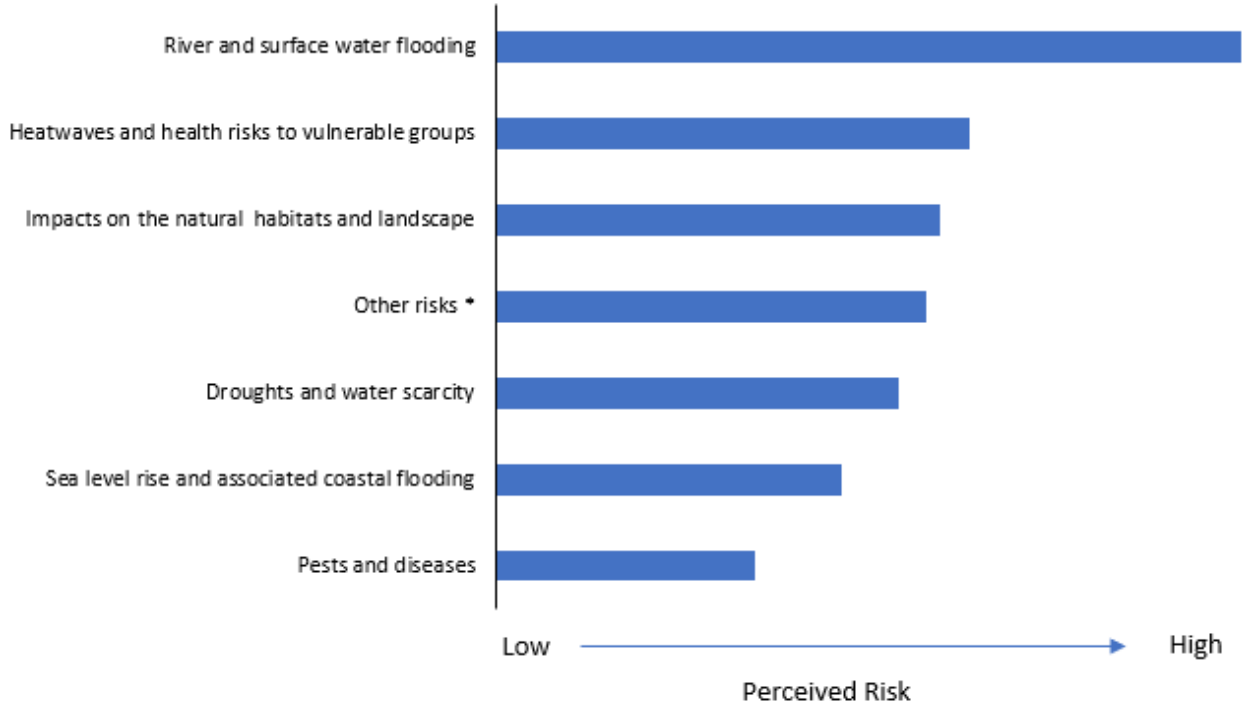


Figure notes: Other risks here represent risks related to cold snaps and severe winter weather that damage roads and require building maintenance as well transition risks related to moving towards net zero, e.g. the higher costs of lower carbon source of heat.

5.2. Planned adaptation

A large number of institutions across Greater Lancashire need to adapt to climate change. The Climate Change Act 2008 includes an Adaptation Reporting Power that requires Government Departments, utilities and some other business to report on their progress on climate adaptation. More recently, private sector organisations are disclosing more information on how they manage climate risks to their investors and shareholders.

Table 5-3 provides some examples of ongoing and planned adaptation in the region and example actions.

Table 5-3 – Climate change adaptation strategies and plans in Lancashire

Theme	Key Strategies and Plans	Example climate resilience actions
Health and Wellbeing	The NHS Long Term Plan[63] Pennine Lancashire CCGs Severe Weather Plan – Including the Flood Plan[64] Central Lancashire Local Plan: Integrated Assessment Scoping Report[65]	NHS Heatwave Alert System Food Resilience Alliance Cosy Homes in Lancashire (CHIL)
Energy	Electricity North West[66]	Improving flood resilience at electricity sub-stations Tree-cutting programmes to reduce windstorm risks to overhead power lines

[63] NHS (2019). The NHS Long Term Plan. Available at: https://www.longtermplan.nhs.uk/wp-content/uploads/2019/01/nhs-long-term-plan-june-2019.pdf
[64] NHS (2020). Pennine Lancashire CCGs Severe Weather Plan – Including the Flood Plan (Incorporating Blackburn with Darwen and East Lancashire CCG)
[65] Preston City Council (2019). Central Lancashire Local Plan: Integrated Assessment Scoping Report. Annexe 1: Plans, Policies, Programmes, Strategies and Initiatives (PPPSI) Review. Available at: https://www.preston.gov.uk/media/1856/Central-Lancashire-Local-Plan-Annexe-1-document/pdf/CL_PPPSI_Consultation_DRAFT_August_2019.pdf?m=637013114313370000
[66] Second round of climate change adaptation reporting (publishing.service.gov.uk)

Theme	Key Strategies and Plans	Example climate resilience actions
	EDF Energy Adaptation Power Report (2nd round) covers actions completed at Heysham NHS. Our Big Plan: Strategy 2021-24[67] Central Lancashire Local Plan: Integrated Assessment Scoping Report	Existing and new nuclear designed to a very high standard to be resilient to extreme events including future climate change. LCC promote design measures for passive cooling in schools and public building contracts.
Transport	Highways Agency Network Rail Peel Ports have not submitted an ARP report. Local Transport Plan 2011-2021[68] Central Lancashire Local Plan: Integrated Assessment Scoping Report	HA integrate climate change integrated into drainage design for all new schemes NR plan for higher temperatures and flood resilience for all network upgrades LCC have improved the specification for asphalt to reduce risks of road buckling/melting.
Agriculture and Forestry	Central Lancashire Local Plan: Integrated Assessment Scoping Report	Farmers and landowners are adapting to climate change through a range of actions on choices of crops, woodland creation, improved soil management, livestock management and water abstraction. Foresters are taking a long term view with respect to the choice of tress for planting.
Water	Central Lancashire Local Plan: Integrated Assessment Scoping Report United Utilities Water Resources Management Plan and Drought Plan Water Resources West Regional Water Resources Plan United Utilities Adaptation Progress Report 2015 under the Climate Change Act 2008[69]	United Utilities develop long term plans that include climate change, as well promoting water efficiency and catchment restoration, including peat restoration projects LCC promote design measures for water efficiency and, in some cases, rainwater harvesting, in schools and public building contracts.
Flood and coastal risk management	Central Lancashire Local Plan: Integrated Assessment Scoping Report Environment Agency Shoreline Management Plan[70]	Flood risk and drainage schemes incorporate precautionary climate change allowances. Promotion of natural flood management schemes, where effective, to reduce river flooding. Sand dune and saltmarsh restoration as nature-based solutions to coastal flooding (e.g. Fylde sand dunes). Promoting a “hold the line” strategy as part of the SMP, which may include hard and soft flood risk and coastal erosion management measures.

Recommendation: Complete a more detailed stocktake, making note of what climate scenarios are being used for adaptation to understand if Lancashire is well adapted to 2°C, 3°C or 4°C world.

[67] NHS (2021). Our Big Plan: Strategy 2021-24. Available at https://www.lancsteachinghospitals.nhs.uk/download/doc/docm93jijm4n9500.pdf?ver=17898. Note that this plan incorporates energy efficiency measures.
[68] Lancashire County Council (2013). Local Transport Plan 2011-2020: Central Lancashire Highways and Transport Masterplan. Available at: https://www.lancashire.gov.uk/media/234521/Environment-report.pdf
[69] United Utilities (2015). Adaptation Progress Report 2015 under the Climate Change Act 2008. Available at: https://www.unitedutilities.com/globalassets/z_corporate-site/cr-images/cr-pdfs/adaptation-progress-report-uu.pdf
[70] Shoreline Management Plans – North West Coastal Group (mycoastline.org.uk)

6. ‘Adaptation in Action’

This section presents four examples of climate adaptation and resilience in Lancashire.

6.1. Fylde coast sea-defences

Climate risk

Historically, parts of North Lancashire have been badly affected by storm-surge. On 11th November 1977 a storm tracked across the UK, with gale force winds of 50 knots reported in the Irish Sea[71]. The arrival of the low-pressure system coincided with spring tides and heavy rain, flooding 1800 properties in the towns of Knott End, Pilling, Morecambe, Fleetwood, Lytham and Blackpool[72].

Figure 6-1 – Damage at Rossall & Cleveley following the February 1977 floods **Source: Wyre Borough Council[73]**

Adaptation benefits

- Sea-defences have been developed and maintained at strategic locations along the Fylde coast including nature base solutions, such as Fylde sand dunes[74] to the south of Blackpool as well as more traditional hard engineering measures such as Cleveleys, to the north of Blackpool
- At Cleveleys the completed length of defences protect 7693 properties from tidal flooding, with less than a 0.5% risk of breach in a given year[75]
- The stepped revetment and split-level promenade dissipate wave energy, reducing the risk of overtopping during a storm surge.

Figure 6-2- Cleveley promenade today

Source: www.visitlancashire.com

[71] Met Office, (1977). Monthly Weather Report of the Meteorological Office. Monthly Weather Report, 94(11). Available at: http://www.metoffice.gov.uk/learning/library/archive-hidden-treasures/monthly-weather-report-1970s
[72] Posner, D. (2004). Wyre Flood and Coastal Defence Strategy Plan, Poulton-le-Fylde, Lancashire.
[73] Wyre Borough Council, 2013. Wyre Urban Core Strategy: Strategy Appraisal Report, Poulton-le-Fylde, Lancashire.
[74] Fylde Sand Dunes Project | The Wildlife Trust for Lancashire, Manchester and North Merseyside (lancswt.org.uk)
[75] https://www.visitcleveleys.co.uk/about/seafront/

Adaptation co-benefits

- The promenade has been dubbed the 'People's Promenade', winning over 20 awards in recognition of the value of the public space, including the North West Tourism Award for the Best Public Space in the North West.
- The stepped revetment was manufactured locally at Hillhouse Industrial Estate in Thornton, and doubles-up as tiered seating.
- Ramp access between the two sections of the promenade and onto the beach creates a community leisure amenity that can be enjoyed and accessed by all.[76]
- Celebration of local heritage is promoted through the 'Mythic Coast Trail', completed in 2010. A story blending local history and legend is told through a series of dramatic sculptures. Subjects as diverse as ogres, shipwrecks and petrified forest (visible at low tide) are brought to life for the public[75].
- The Fylde sand dunes project has created more 6 hectares on new sand dune habitats, recreation and education opportunities as well providing flood and erosion protection.

Figure 6-3 Fylde sand dunes

Source: Lancashire, Manchester and North Merseyside Wildlife Trusts

6.2. Peatland restoration in upland catchments

Climate risk

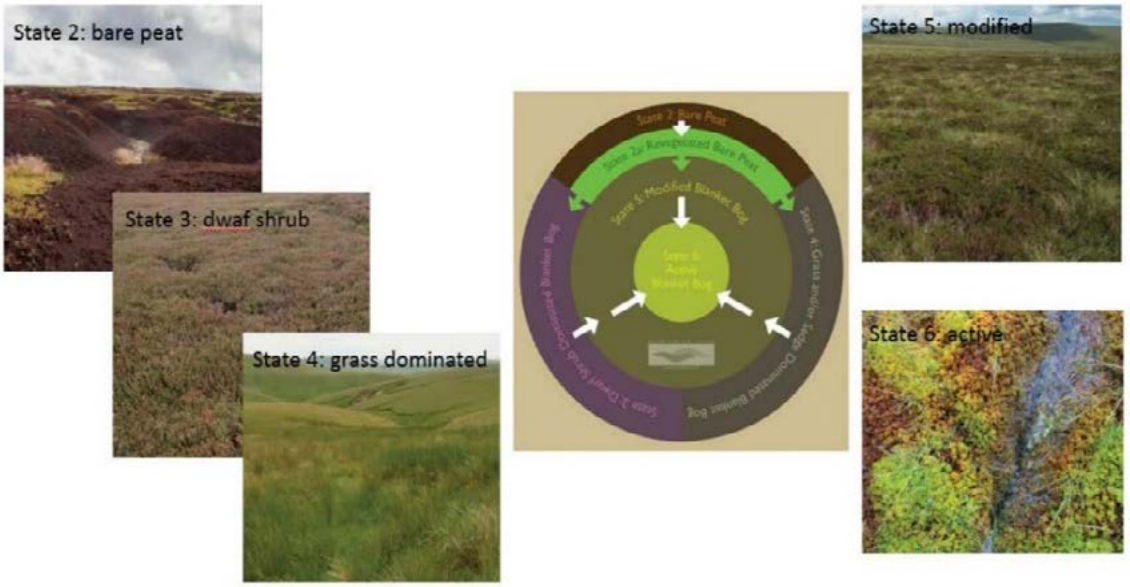
- Currently, 70% of UK drinking water comes from upland areas dominated by peatlands[77]. However, a legacy of unsustainable management practices including overgrazing and peat drainage, along with projected climate changes such as more frequent wetting and drying cycles, are creating a range of challenges.

[76] https://www.youtube.com/watch?v=S6dp1Y7Sqis
[77] International Union for Conservation of Nature IUCN

- Degraded peatland is more at risk from wildfire, due to lower soil water content and drier vegetation. The Winter Hill wildfire of 2018 burned 4000 acres of moorland and took 40 days to extinguish[78], at an estimated overall cost of £500,000.
- The water quality of key peatland water sources has steadily declined as peatland carbon dissolves into watercourses, adding additional expense to the downstream water treatment process.

Adaptation benefit

Figure 6-4 – Six states of peatland restoration



Source: United Utilities, Accelerating Partnerships to deliver Natural Solutions (2021)

- United Utilities utilised investment through the Sustainable Catchment Management Programme (SCaMP) to bring about a shift since 2005 from state 2 (bare peat) to state 3 (dwarf shrub) across their upland estate. At Winter Hill this was achieved through de-stock grazing and gully blocking. Recent proposals promote further advancement from state 3 to states 4 (grass dominated) and state 5 (modified) by increasing the diversity of the vegetation and removing artificial drainage features.
- Since the 2018 wildfires, a new Lancashire 'wildfire burn team' based at Bacup fire station has been trained and equipped with specialist gear to rapidly respond to fires and intervene as early as possible to minimise the extent of damaged moorland.
- In May 2021, it was reported that degraded peatlands in the Pennines will be re-wetted and replanted as part of a £30m project funded by UK Research and Innovation to test effective and affordable ways of removing CO_2 from the atmosphere[79].

Adaptation co-benefits

- Carbon storage is maximised in restored peat soil.
- Reduced flooding from delayed surface runoff
- The additional processing required to treat poor-quality water may be avoided. Additional processing can reduce a water treatment works throughput, potentially impacting local and regional water supply. On the Fylde Coast if a deficit in supply had to be made up with new sources this would come at an estimated cost of £55 million.

[78] https://inews.co.uk/news/climate-change-is-making-wildfires-so-frequent-and-large-that-a-dedicated-task-force-has-been-set-up-in-lancashire-320514
[79] The Guardian, 24 May 2021: https://www.theguardian.com/environment/2021/may/24/trials-to-suck-carbon-dioxide-from-the-air-to-start-across-the-uk

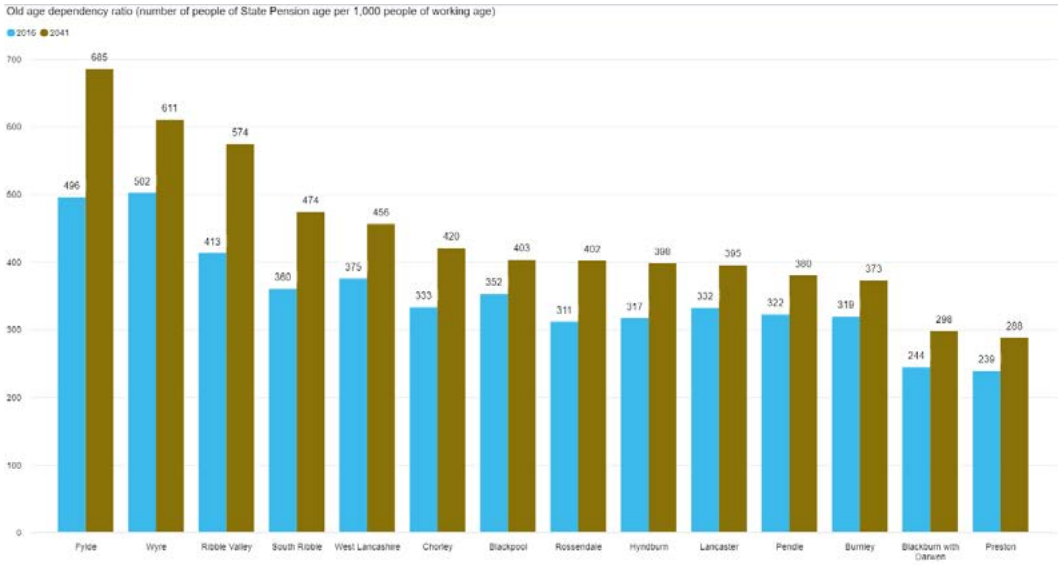
- Securing multiple sources of reliable water increases the opportunities available to the North-West as a donor region in future water trading agreements.

6.3. Heatwave adaptation

Climate risk

- Periods of prolonged heat cause excess deaths. Following the 2009 heatwave there were approximately 300 excess summer deaths in England, with the majority of deaths in over 75 year olds.
- Along with the rest of the UK, Lancashire faces the social and economic challenges associated with an ageing population. The old age dependency ratio (the number of people on state pension per 1,000 people of working age), is predicted to increase in every district over the period of the projection, with Fylde seeing the largest increase by 2041 (**Figure 6-5**).

Figure 6-5 - Lancashire demographic projections (2016 – 2041)



Source: Lancashire County Council (www.lancashire.gov.uk)

Adaptation benefit

- In May 2020 a Level 2 heatwave alert was issued by the Met Office. In accordance with the heatwave plan, local Clinical Commissioning Groups including East Lancashire CCG began public health messaging, particularly emphasising the precautions to be considered by the most vulnerable high-risk groups[80]. Nursing and care homes were informed of relevant guidance.
- The Pennine Lancashire CCG Extreme Weather Plan states: "Even during relatively mild heatwaves, excess deaths are significantly but avoidably higher in this county. Timely preventative measures can reduce these excess rates"

Adaptation co-benefit

- Implementation of the government's proposed '10 Year Plan for Adult Social Care' has the potential to provide important co-benefits in terms of heat-related illness and deaths in older people.
- Lancashire CCG emphasise the potential multiple benefits that come from making progress on the Public Health Outcomes Framework indicators relevant to heatwaves. These are:
    - Improving social connectedness is good for general well-being, as well as enabling people to more easily access the help they need to protect themselves from severe heat;

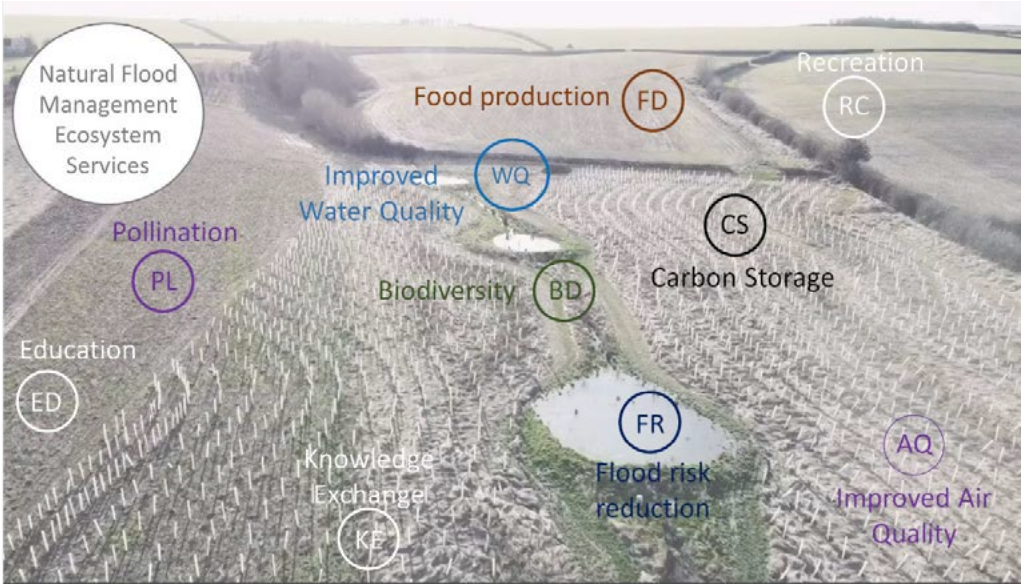
[80] https://eastlancsccg.nhs.uk/news/1066-keep-safe-heatwave-predicted-for-wednesday-to-friday-this-week

- Encouraging walking and cycling will improve health as well as air quality (poor air quality may worsen during periods of increased temperatures)
- Provision of green space is beneficial for exercise/health reasons, as well as reducing urban heat.

6.4. Wyre Natural Flood Management – a pilot natural capital project

National pilot projects have demonstrated the benefits of landscape scale Natural Flood Management for both reducing flood risk and delivering a range of benefits, which contribute to climate change mitigation and adaptation[81]. These include improving soil health, so that it can store increased carbon and water, planting of woodlands, wetlands and re-introducing river meanders to create a more natural and diverse river environment.

Figure 6-6 – Multiple benefits of Natural Flood Management schemes



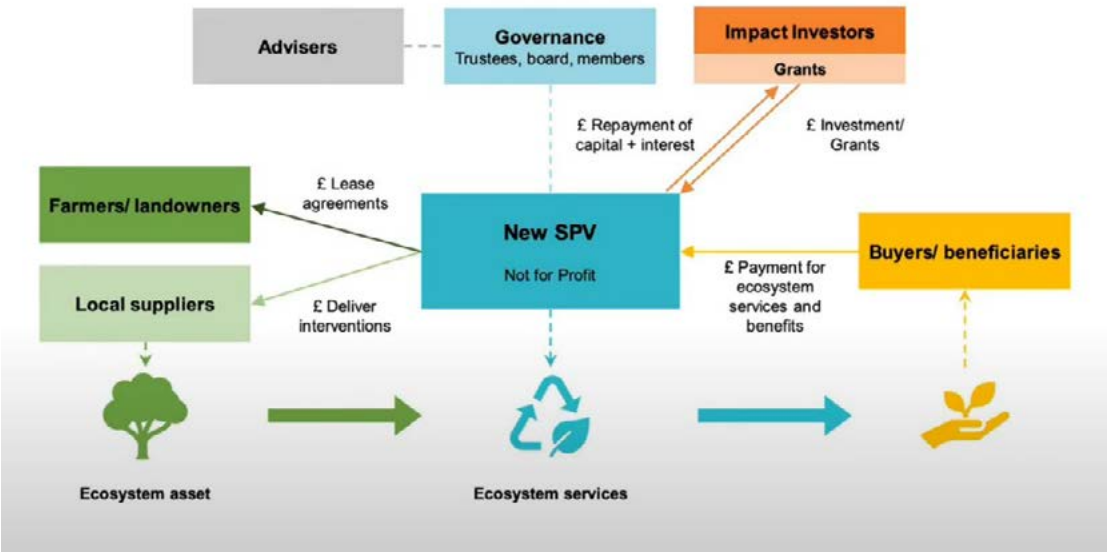
Source: Atkins Littlestock Brook, Evenlode national NFM pilot

Climate risk

- Flooding regularly occurs in the Wyre catchment (1927, 1980, 2015 and 2016) and the risk of flooding from sewers, surface water and rivers in the region is projected to increase under climate change.
- In the past the typical response has included maintenance, drainage and hard flood defence structures. These solutions are often expensive, unsustainable and do not take sufficient account of the River Wyre, its ecology and processes.
- Natural Flood Management (NFM) involves slowing the flow of water and increasing storage in the catchment to reduce the height of flood peaks. The mechanisms to finance the implementation of NFM at scale in the UK remain a significant barrier to its uptake.

Figure 6-7 - Possible green finance funding model explored by the project

[81] Using the power of nature to increase flood resilience - GOV.UK (www.gov.uk)



Source: Presentation given at the Greater Manchester Green Summit (2020)

Adaptation benefit

- The pilot project aims to bring together partners who have a vested interest in understanding the effectiveness of natural flood management in order to explore viable alternative funding streams. Partners include Triodos Bank, Co-op Insurance, United Utilities, The Rivers Trust, the Wyre River Trust, the Environment Agency and Flood Re.
- The project aims to discover what beneficiaries are prepared to pay for and to explore how NFM can be funded at the scale and pace required to make a difference.
- NFM interventions such as leaky dams and water retention ponds are being delivered by 10 landowners in the upper catchment, with further intervention considered in urban areas in the lower catchment through Thornton Flood Risk Resilience group.
- Initial modelling of the River Wyre catchment has shown that the development of approximately 70 hectares of NFM features could reduce the frequency of flooding for up to 120 properties in Churchtown[82].

Adaptation co-benefit

Figure 6-8 - Volunteers helping to install NFM features in the upper Wyre catchment. Source: Wyre Rivers Trust

- Multiple beneficiaries including the water company, Environment Agency, local authorities, insurance industry, locally based businesses and homeowners.
- Three funding streams are being explored, including carbon sequestration through tree planting, biodiversity gain, and improved water quality.
- The project builds on the work of proactive community flood action groups including Churchtown Flood Action Group.
- Environmental benefits include boosted biodiversity and improved water quality.

[82] https://thefloodhub.co.uk/wyre-nfm-project/

7. Climate Resilient Lancashire

7.1. Case for adaptation or resilience

There is a strong case for funding climate resilience and adaptation, with respect to:

- Avoiding impacts from climate change including both financial and non-financial impacts (e.g. property damage, deaths).
- Benefits from climate change opportunities.
- Other direct benefits, e.g. in terms of improved health and biodiversity and supporting Net Zero ambition.
- Indirect benefits through employment and related induced impacts.

Early investment in climate resilience is cost effective and reduces costs, compared to delayed action.

Recommendation: It is recommended that the economic strategy reviews the Lancashire infrastructure pipeline of major projects (transport, energy, water, tourism projects) to identify planned resilience measures and any opportunities to enhance the value of proposed projects to deliver climate resilience benefits.

7.2. Sector opportunities

As well as risks, climate change also offers some opportunities. The CCRA3 identified a number of opportunities related to climate change and Lancashire is well placed to benefit from opportunities related to biodiversity, agriculture and forestry as well as warmer temperatures that may influence the attractiveness of the region to visitors as well as reduce winter heating requirements (**Figure 7-1**). Opportunities related to the Environmental Land Management (ELM) and carbon storage could be mapped across the region along with information on how new environmental schemes will operate.

Figure 7-1 – CCRA3 opportunities related to future climate change

7.3. Sustainable finance

There is no single source of funding for climate change adaptation or resilience. In the short term, climate resilience will need to be funded as an integral part of existing funding mechanisms, which include:

- Flood risk and coastal erosion management (FCERM) schemes, which include climate change adaptation and are increasingly seeking multiple benefits.
- Transport infrastructure projects, which provide opportunities to create a more resilient road network and to reduce flood risks and potentially improve air quality for local communities.
- New developments, which need to respond to local design guidelines and make contributions to community infrastructure (roads, schools, open space, drainage etc.)
- Water company investments, which increasingly include wider river basin management to improve water quality as well large programmes to promote water efficiency, reduce surface water flooding and improve bathing waters.
- New health and social care infrastructure, including hospitals.

Therefore, local authorities have an important role to identify opportunities to influence promoters to enhance their project's value, including delivering climate change resilience benefits.

In the longer term, it is anticipated that green finance could become more important and could create the right market conditions for adaptation funding if it is integrated as a core aim in proposed projects. Some examples of recent developments in green finance include the use of green 'resilience bonds', which have been used to fund Net Zero and resilience projects in the UK and Europe.

Green finance offers the potential to fund adaptation actions with wide-ranging benefits across climate change mitigation, adaptation and biodiversity protection. The UK Government's Green Finance Strategy identifies climate resilience and an increase in adaptation as strategic objectives to support through green finance. Despite this recognition, the Government does not provide further details on providing funds or financial mechanisms for these goals.

7.4. Delivering 'Climate Resilient Lancashire'

The declaration of a Climate Emergency and regional economic policy require a step-change in the promotion of a 'Climate Resilient Lancashire', which goes beyond incremental increases in adaptive capacity and towards more transformational changes to the region's economy, society and environment.

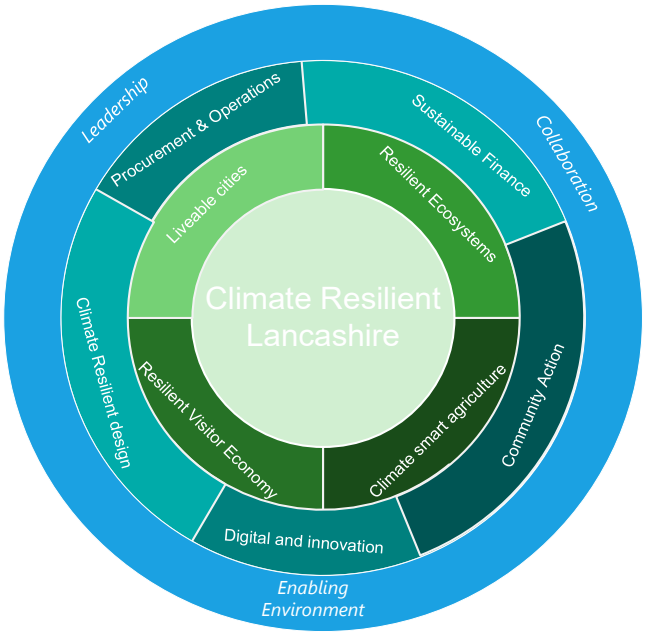
The CCRA3 report highlights seven different types of climate change adaptation from institutional changes, such as developing standards, regulation, and guidelines, through to changes in the financial sector, which aims to shift financial flows towards projects that promote sustainable development and climate action.

Based on our review, the unique and varied geography of Lancashire and selected interviews we have proposed an outline framework for Climate Resilient Lancashire including potential outcomes and possible high-level adaptation activities (Figure 7-2, Table 7-1). Potential outcomes include:

- Liveable cities that integrate blue-green infrastructure, promote active travel and reduce the risks of flooding and overheating due to climate change.
- Resilient ecosystems (coastal, uplands and lowlands) that provide a range of services including biodiversity gain, natural flood management and carbon storage.
- A Resilient Visitor Economy, that attracts visitors to the region for traditional holidays, active holidays and business, making use of the long coastline and varied Lancashire landscapes and amenities.
- Climate smart agriculture, allowing both highly efficient production and environment enhancements using digital technologies for commercial and environmental benefits as well as allocating land for Environmental Land Management (ELMs) schemes.

Recommendation: This initial view of a Climate Resilient Lancashire requires further refinement and co-development with local authorities and other partners across Lancashire as part of the economic strategy or as part of a regional Climate Change Strategy.

Figure 7-2 – Climate Resilient Lancashire: Outline framework, potential outcomes and themes



Adaptation actions:
1. Institutional leadership, standards, regulations
2. Behavioural change
3. Engineered solutions
4. Nature-based solutions
5. Data and R&D
6. New or emerging technologies
7. Financial disclosure, green finance, adaptation finance and insurance

Resilient Places:
Urban centres
Coasts
Uplands
Lowlands

Potential Opportunities:
1. Biodiversity gain, agricultural outputs and forestry
2. Food production, manufacturing and exports
3. Business and trade in adaptation services

A Climate Resilient Lancashire requires the right enabling environment with collaboration between local authorities, the Environment Agency, NGOs and the private sector. Key activities include promoting climate resilient design, embedding climate resilience in procurement and operations enabling community action in areas of importance to them, which may include initiatives around a wide range of issues, for example, environmental quality, sustainable consumption or local food production.

The CCRA3 identified ten principles of good adaptation; Table 7-1 provides some recommendations against these ten principles, cross-referenced to the framework in Figure 7-2. Table 7-2 summarises some example actions on a sector by sector basis.

Table 7-1 – High level recommendations for a Climate Resilient Lancashire

Good adaptation principles	Recommendations and example adaptation actions	Reference to framework
A vision for a well-adapted Lancashire	The Economic Strategy represents a vision for Lancashire that includes climate resilience as well as Net Zero Develop a regional climate adaptation strategy that aims to deliver resilience and empower organisations to contribute to Net Zero and resilience targets. Hold a collaborative climate resilience workshop as part of the Lancashire Environment and Climate Summit involving all authorities, utilities and community organisations Development of clear resilience goals and targets to sit alongside the target for Net Zero. Establish regional governance mechanisms to promote transformational adaptation (public-private-community partnerships)	Enabling environment, leadership and collaboration
Integration of adaptation into other polices	Stocktake of policies to ensure inclusion of both Net Zero and resilience; this is already happening in some authorities with all council papers including sections on climate change.	Enabling environment,

Good adaptation principles	Recommendations and example adaptation actions	Reference to framework
	Development of climate resilience design guidelines and standards for inclusion of climate resilience in spatial planning, housing design, transport and other sectors. Consideration of climate resilience in authority procurement, including supply chain commitments to Climate Action and specification of climate guidelines and standards. Review regional infrastructure pipeline and identify climate resilience requirements and potential enhancements to add value. *Note that climate risks are well integrated in flood management plans, coastal strategies and UUs water resources management plans, which may offer some opportunities for joint projects.*	leadership and collaboration Climate Resilient Design Procurement and Operations
Assess risks for 4°C above pre-industrial	To develop a clear policy position on what scenarios to plan for and how to deal with uncertainties in future climate risks. Raise awareness of potential risks using policy relevant metrics and indicators (as provided in Section 4). Work with key economic sectors to understand risks and support climate risk disclosure.	Cross-cutting
Avoid Lock-In	Climate Emergency forums to consider climate resilience as well as Net Zero as targets will not be met without resilient ecosystems and infrastructure projects. Ensure that all new homes, buildings and other infrastructure is resilient to a range of future climate conditions, including scenarios of 4 °C above pre-industrial (RCP6.0 and above); develop guidelines for spatial planning and new development. When buildings or infrastructure are modernised consider long term risks and retro-fit climate adaptation options, including incorporation of blue-green infrastructure corridors and requirements for passive/active cooling in schools, hospitals and housing.	Climate Resilient Design
Prepare for extremes	Promote the use of regional heatwave plans and ensure that the health and social care sectors are prepared for hotter summer conditions. Maintain wildfire plans and raise awareness of risks in advance of hot and dry conditions Promote flood resilience on the local authority estate and for all businesses exposed to flooding Stress-test regional transport systems against extreme climate scenarios and have contingency plans ready Ensure that communities are signed up to Environment Agency Flood Warning schemes Trial bespoke weather services to provide early warnings e.g. local gritting service for cold snaps, medium-range forecasting if heat extremes	Climate Resilient Design & Community Action Digital and Innovation
Assess inter-dependencies	Promote a better understanding of the linkages between Net Zero and resilience as nature-based solutions must be climate resilient in order to store carbon. With greater reliance on electricity, rather than gas for heating, work with electricity providers to understand risks and ensure resilient electrical supplies.	Cross-cutting

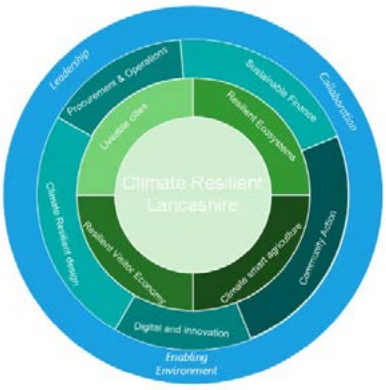
Good adaptation principles	Recommendations and example adaptation actions	Reference to framework
	Work with businesses to understand the climate risks to supply chains.	
Understand thresholds	Develop operational processes for recording weather and climate impacts on local communities, transport, local authority estates etc… to build a better picture of climate thresholds and impacts on the region. Engage with the university sector to establish city and regional observatories for climate and environmental monitoring, including potential impacts	Procurement & Operations Cross-cutting
Address Inequalities	Work with communities at risk to build their adaptive capacity and resilience to floods, heat extremes and other hazards. Map existing networks of community groups e.g. climate emergency assemblies, flood forums, sustainable food groups, “Pre-loved” community groups, faith groups etc…involved in sustainable development and climate action. Provide support, guidance and tools to enable local communities to contribute to Climate Action.	Community Action
Consider opportunities	Review and map opportunities for nature-based solutions including new crops and forestry that meet multiple objectives, such as carbon storage, biodiversity and natural flood management. (Blackburn with Darwen completed some mapping as part of their Local Plan). Following prioritisation of potential schemes, develop a comprehensive programme for delivery of ‘green infrastructure’ and nature-based solutions that provide both carbon storage and climate adaptation benefits. Review opportunities for manufacturing of environmental sensors and other goods, anticipated to be in high demand due to climate change. Review comparative advantage of local agricultural supply chain compared to the rest of the UK and Europe. Opportunities for business and trade in adaptation and resilience services.	Sustainable Finance
Funding, resourcing, metrics, research	Mobilise to unlock sustainable finance through strategic use of available public resources and private sector investments. Map sources of finance and their requirements for delivering sustainable development and Climate Action Develop clear business cases for early adaptation, to save costs in the longer term. Encourage large organisations to plan for climate change and to disclose their climate risks, following the recommendations of the Task Force for Climate Related Financial Disclosures (TCFD) Work with universities and private sector to establish a research hub for Net Zero and climate resilience.	Sustainable Finance

Table 7-2 provides some examples of possible adaptation options as well as indicative benefits. The options are detailed by sector, however adaptation can often yield benefits across multiple sectors, for example, increased urban greenspaces could help flood management, provide mental health benefits, increase biodiversity, and reduce the impact of heatwave events.

Table 7-2 – Examples of adaptation options and potential benefits by sector

Sector	Adaptation (and related mitigation actions)	Benefit
Health and Wellbeing	Increased investment in walking and cycling schemes; active travel and other actions to reduce emissions in areas of poor air quality. Ensure sign up to NHS Heatwave Alerts and link to contingency plans for social care. Promote links between healthy eating and climate change as part of existing community networks	Reduced health problems through the benefits of exercise. Reduced emissions from travel. Reduce heat related morbidity and mortality Supports local food movement, including growers and improves health.
Energy	Implement measures to manage extreme heat and potentially high cooling demand, incentivising passive cooling where possible. Promote water efficiency measures that also reduce wastage of hot water. Ensure electrical and heating networks are climate resilient. Greater use, and development of, alternative energy sources e.g. Hydrogen	Reduction in cooling and water heating costs Reduction in raw water abstraction from the environment Reliable energy supplies Decarbonisation of a variety of sectors supporting the Net Zero agenda
Transport	Development of improved numerical tools to predict asset failure and plan maintenance Increased use of soft engineering techniques such as vegetation management Promotion of Sustainable Drainage Systems (SuDS) and improved flood protection on new roads and upgraded roads. Climate resilient specifications for resurfacing and other works.	Proactive maintenance can reduce longer terms costs and impacts to travel time Soft engineering solutions can provide natural capital benefits as well as aligning with the Net Zero agenda
Agriculture and Forestry	Research and support to manage the introduction of new crops/varieties and other non-invasive plant species. Larger scale afforestation and peatland restoration as required to meet Net Zero targets	Enhances species richness and can contribute to community adaptation. Alternative agricultural produce may provide access to new markets. Supports natural flood management, improved water quality and the Net Zero agenda through carbon sequestration

7.5. Summary and recommendations



Lancashire's declaration of a Climate Emergency and subsequent developments in regional economic policy require a step-change in the promotion of both Net Zero and a 'Climate Resilient Lancashire', which goes beyond incremental increases in adaptive capacity and towards more transformational changes to the region's economy, society and environment. The region's Net Zero targets will require investment in nature-based solutions to store carbon and deliver other benefits, as well as climate resilient design to avoid the impacts of floods, droughts and heatwaves.

The region is already experiencing higher temperatures and greater exposure to climate extremes. For example:

- Average annual temperatures in the North West of England are already around 1.5°C higher in the 21st century compared with the end of the 19th century
- At Heysham in Lancashire recent rates of sea level rise are around 4 mm/year, a faster rate of change than the long-term average for the UK (1.4 ± 0.2 mm/year), consistent with the upturn the global average sea level rise since 1990.

Without significant increases in the global ambition to reduce greenhouse gas emissions, the region is likely to warm to around 3°C above pre-industrial by the end of the century and could warm by over 4°C with even greater impacts on all economic sectors.

Based on our assessment of the UK Climate Change Projections 2018, a series of interviews on Adaptive Capacity and the unique characteristics of Lancashire we have proposed a framework for delivering Climate Resilient Lancashire. This includes a range of high-level recommendations, which can now be considered as part of the Greater Lancashire Plan and local authority climate action planning. Of these recommendations there are 5 flagship actions that are high priority:

- **Collaboration:** This initial view of a Climate Resilient Lancashire requires further refinement and co-development with local authorities and other partners across Lancashire as part of the economic strategy or as part of a regional Climate Change Strategy. Lancashire's authorities need to work in partnership with other organisations to deliver climate resilience, including the NHS, the Environment Agency and emergency services (Section 5.1).
- **Climate Resilience Stocktake:** Complete a more detailed stocktake of Lancashire's adaptive capacity and existing adaptation and resilience planning (including utilities, government agencies, private sector and NGOs), making note of what climate scenarios are being used for adaptation to understand if Lancashire is well adapted to 2°C, 3°C or 4°C world (Section 5.2) and to identify any gaps requiring urgent action.
- **Climate resilient infrastructure:** The economic strategy reviews Lancashire's infrastructure pipeline of major projects (transport, energy, water, tourism projects) to identify planned resilience measures and any opportunities to enhance the value of proposed projects to deliver climate resilience benefits. Climate change design guidelines should be identified or developed for each major infrastructure sector (Section 6 and Section 7).
- **Sustainable finance:** Both identification of opportunities and funding of adaptation and resilience is a challenge. The partnership should work together to map opportunities (e.g. for nature-based solutions) and identify funding streams within and between specific sectors (Section 7). As part of the vision for Lancashire, the strategy should define clear sustainability goals, including a goal for climate resilience that can be tracked alongside goals for net zero.
- **Community action:** Climate resilience requires action at all levels, including behavioural changes to promote sustainable consumption, water efficiency, a circular economy and active lifestyles. The partnership should map community groups and seek to provide further resources to empower local communities to take action on reducing emissions and to be prepared for climate change (Section 7).

Appendix A.

A.1. Literature Review

A.1.1. Coastal

Lancashire's coast is the most sensitive area of the county to climate change. A large proportion of it is low-lying and at risk from sea water flooding caused by raised sea levels and increased frequency of storm events. Increases in wind speed are likely to raise wave heights, thereby enhancing the risk of flooding in unprotected areas and contributing to heavy beach erosion. In turn, this may adversely affect mudflats and salt marshes, which are important habitats for providing natural flood defences and feeding grounds for birds. Temperate marine coastal ecosystems may also be lost due to an increase in temperature or a shift in siltation patterns due to changes in rainfall patterns and wind direction.

Changes in coastal processes, including increased erosion, may require reconsideration of coastal defences in relation to the county's capital-intensive, coastal-based industries and assets. Decisions will be influenced by the options set out in the north-west region's Shoreline Management Plans. These include 'hold the line', 'managed retreat' and 'do nothing'.

Ports may have to invest in more regular dredging in response to change in siltation patterns and hydrodynamic conditions. Other marine-related sectors, such as fisheries and Lancashire's coastal resorts may find their activities affected and disrupted by climate change. Even the design of ships heading into and leaving Lancashire may have to change to cope with the region's higher than average and exceptional wind speeds. Changes in vessel design may, in turn, have an impact on how port infrastructure is configured.

A.1.2. Urban Core and Fringe

As temperatures increase, urban 'heat islands' will become more common and can cause discomfort for those in poorly designed, insulated and ventilated buildings. This will increase the need for cooling services, thus potentially increasing energy costs and other atmospheric pollutants depending on the method of energy generation to provide this service. Additionally, street trees will become increasingly important to provide shelter from the sun and avoid health risks through sunburn. Refurbishment of parks and gardens should take the implications of climate change into account, utilising plants that adapt better to new conditions and providing greenspaces to help counteract heat islands. Furthermore, should there be an increase in homes and offices in the urban area, demands for water and electricity will change. This may have knock-on implications for other areas and activities, e.g. water restrictions for garden irrigation in sub-urban communities.

Due to the displacement of manufacturing industry, water tables are also rising in parts of the urban core and this is likely to worsen with an increase in winter precipitation. In turn, this may cause an increase in flood risk and the possible exposure to toxic substances found on contaminated land, potentially contaminating water systems. Buildings and other infrastructure are also at risk of structural damage from storms, both from the meteorological events themselves and from the knock-on impacts caused.

A.1.3. Rural Lowland

Lancaster's rural lowland region is already heavily modified with existing ecosystems adversely affected by current activities. Climate change is likely to be an additional stress to plant and animal communities, especially species that are unable to adapt or migrate relatively quickly. This may lead to vegetation change, and possibly loss of habitat and species.

An increase in temperature and decrease in summer rainfall may lead to water supply problems, especially for current irrigated farming. This can also contribute to more cracking of land and higher soil moisture content over winter, increasing risk of stream, river, sewer outlet floods, and pollution runoff. In addition to this, farm wastewater systems in the region are not currently designed to cope with increased winter rainfall. Waterlogged soils are also more susceptible to damage from cattle and farm, equipment, limiting time available for working or grazing.

A.1.4. Rural Upland

Lancashire's rural upland region bears highly specialised plant and animal communities that have adapted to the region's colder climate. Thus, a change in temperature or rainfall patterns could cause large impacts on biodiversity. Shifts in rainfall to more intense patterns over shorter periods may cause greater soil erosion, which can contribute to flooding.

A rise in temperature is highly likely to cause other impacts, ranging from species loss and outward migration to the possibility of invasive non-native species or diseases arriving on land or through vectors such as waterways or coastal currents. Changes in biodiversity can affect water supply and transfer, such as causing low water levels and poor quality. If animals are grazing more on exposed young shoots, the lack of vegetation can lead to an increase in flash floods, which can further adversely affect the remaining species and habitats.

Rural upland areas may also be at risk from wildfires, which can further damage biodiversity levels and be expensive to extinguish. The upland areas have significant peat deposits and act as a large storage 'sink' for carbon. However, increases in decomposition rates due to warmer temperatures could release large amounts of the stored carbon, accelerating global warming. Further, should peat deposits catch fire, the underground burning can cause significant damage to biodiversity and associated ecosystems can take decades to recover.

A.1.5. CCRA3 National Flood Risk Assessment

Of these 6 focus areas, flooding from surface water, rivers, and coastal inundation presents the greatest risks to people and the greatest need for action in the short and long term. Due to climate change, flooding is projected to increase substantially across the UK with expected annual damages (EAD) increasing from £2 billion today to £4 billion by the 2080s (under a 4°C future).

Lancashire is particularly exposed to risks from flooding for several reasons:

- The county has been identified as having some of the highest agricultural exposure to flooding across the UK (based on the exposed area for the 3.3% Annual Exceedance Probability or 1 in 30 year flood).
- The northwest of the UK is projected to have a 40% increase in intense rainfall of <6 hours duration by 2050 if global mean surface temperature (GMST) reaches 4°C by 2100, which is higher increase in rainfall intensity than any other region in the UK.
- The influence of climate change is greatest at the coast, especially when the rise in global temperatures exceeds 2°C, with expected damages from flooding rising by a further 70% under a 4°C rise scenario compared to 2°C.
- The northwest coast is more vulnerable to simultaneous river and coastal flooding events than any other UK coastline.

An estimated 1.8 million people live in areas with a 1.3% or greater annual chance of surface water, river or coastal flooding. This is expected to rise to 2.6 million by 2050 under a 2°C scenario and 3.3 million under a 4°C scenario. The number of properties with greater than 3.3% annual probability of flooding is projected to increase from 240 000 to 280 000 by 2060. These estimations assume that Lancashire's population growth is low and that current levels of adaptation are maintained. In the absence of adaptation strategies, EAD could increase £9bn with a 4°C climate change and high population growth.

Global sea levels are predicted to rise 50-100 cm by 2100, which will exacerbate flood risks and accelerate the process of coastal change for exposed communities. Indeed, it could make 200 km of English coastal flood defences (20% of England's total coastal flood defences) highly vulnerable to failure in storm conditions. If the aspirations of Shoreline Management Plans in England are to be met, then the rate of coastal managed realignment needs to increase five-fold to compensate for the increasing costs associated with rising sea levels and increasing storm intensities.

Resilience measures are, therefore, required but to be economically justifiable must often focus on adaptation to existing infrastructure. This has other benefits that would improve well-being alongside implementing resilience, including increasing (rather than limiting) urban green space, using sustainable urban drainage systems (SuDS) instead of overloading drainage systems and favouring natural flood management over hard engineered structures. SuDS not only mitigate surface water flooding but also benefit biodiversity, air quality, ecosystems, water resources and health and well-being. In 2016 the EA announced £15 million specifically for investment in natural flood management projects in England.

EAD could reduce by 11% under a 2°C scenario if 'Enhanced Whole System' (EWS) adaptation is pursued between now and mid-century. Note that EWS includes property level protection as well as local action. Beyond 2050, and under a 4°C rise, EAD will continue to rise under EWS.

A.2. Further information on climate change scenarios and indicators

A.2.1. Methodology for calculation of climate indicators

Atkins analysis has applied results, data and figures from three recent studies (Arnell et al., 2020; N. Arnell and Freeman, 2021; N. W. Arnell and Freeman, 2021 – in publication).

In these studies, the climate projections were applied to observed climate data (HadUK-Grid) by considering the change in parameters (the delta change method).

The reference period against which climate change was compared is 1981-2010 (sea level rise: 1981-2000). All indicators were calculated from daily weather data to produce time series of annual total or accumulations.

Global, regional, and probabilistic strands were applied to give three sets of projections, each with a different purpose. All indicators are expressed as climate averages over 30 years. Results are shown for three climate scenarios based on the IPCC's Representatives Concentration Pathways (RCPs): RCP 2.6 – low; RCP 4.5 - medium-low or RCP 6.0 - medium; and RCP 8.5 – high.

The analysis is focused primarily on RCP 8.5 as based on the recent trajectory of global emissions and to highlight potential risks for Lancashire.

UKCP18 offers a range of different products and the products used are summarised in Table A-1 below, along with the indicator definition. For further details and references for each indicator refer to Arnell et al., 2021.

Table A.1 List of climate indicators

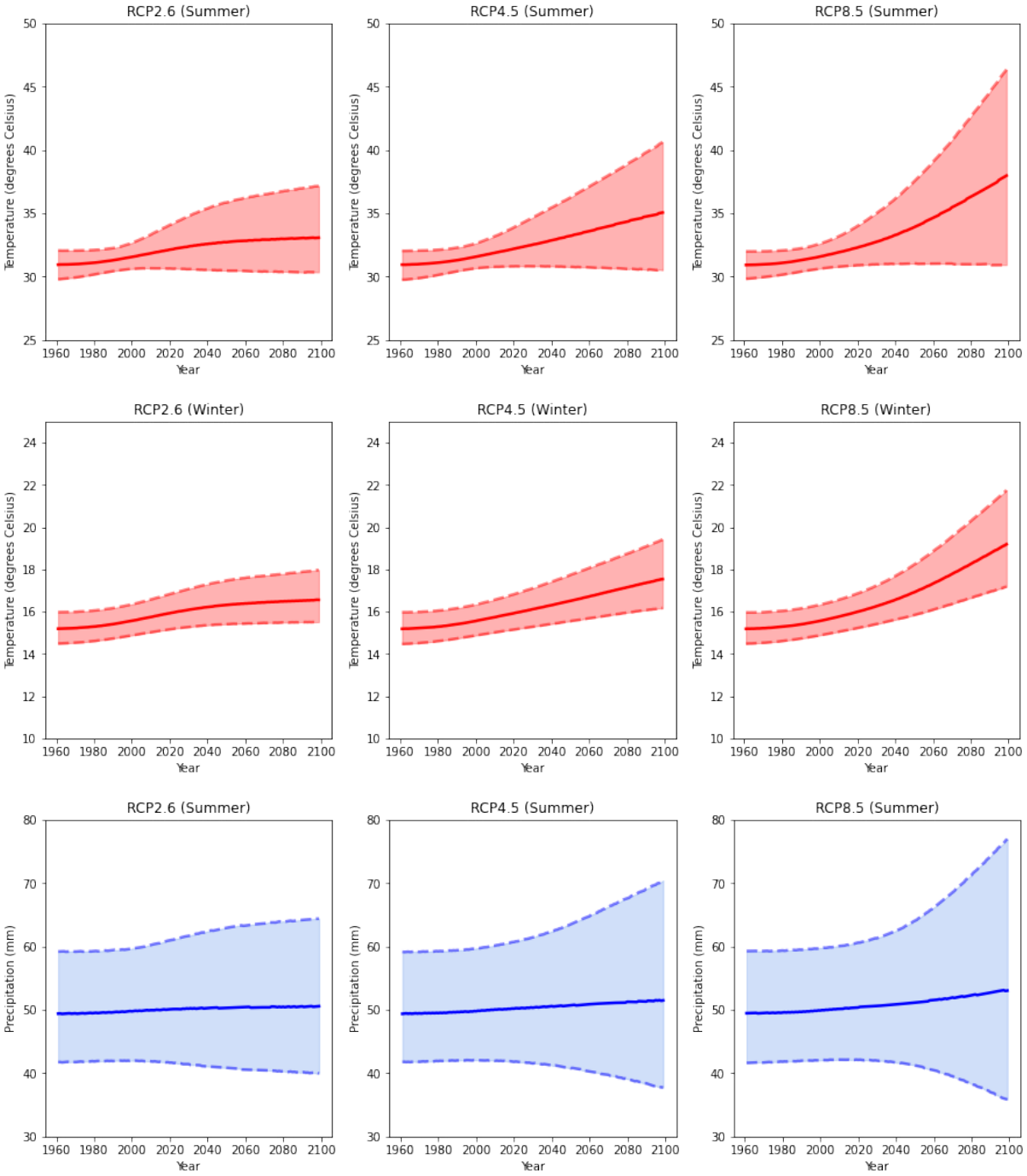
Indicators[1]	Definition	UKCP18 Projections
Health and wellbeing		
Activation of NHS England Heatwave Plans ("Amber alerts")	Maximum and minimum temperatures above region-specific thresholds for at least two days 25ºC	Probabilistic
Met Office heatwave	Maximum temperature above region-specific thresholds for at least three days; Day - 30/ Night - 15ºC	Probabilistic
Activation of NHS Cold Weather Plans	Average temperatures below 2°C for at least two days	Probabilistic
Energy use		
Heating degree days	Heating degree days relative to 15.5ºC	Regional
Cooling degree days	Cooling degree days relative to 22ºC	Regional
Transport		
Transport network risk: 26ºC	Maximum temperature above 26ºC	Regional
Rail network risk: 30ºC	Maximum temperature above 30ºC	Regional
Railway adverse weather days	Max temperature above 25ºC, or min temperature below -3ºC, or daily rainfall > 40mm, or snow depth > 50mm.	Regional
Agriculture		
Growing degree days	Sum of degrees above 5.6ºC during the thermal growing season	Probabilistic
Growing season length	Days between start of growing season and first of five consecutive days with average temperature	Probabilistic
Growing degree days	Sum of average temperatures above 5.6 °C (°C - days)	Probabilistic
Wheat heat stress during anthesis	Days between 1 May and 15 June with max temperature greater than 32ºC	Probabilistic
Agricultural drought risk	Time with the Standardised Precipitation Evaporation Index (SPEI) < -1.5. SPEI calculated over 6 months.	Probabilistic
Start of growing season	The first of five consecutive days with average temperature >5.6 °C (day of year)	Probabilistic
Potential soil moisture deficit	Annual maximum potential soil moisture deficit, calculated from potential evaporation and precipitation.	Probabilistic
Heat stress effect on milk yield	Days with temperature humidity index >70 (days/year)	Probabilistic
Parasite outbreaks in sheep	Days with average temperature > 9 °C (days/year)	Probabilistic
Hydrological		
Severe hydrological drought	Time with the Standardised Streamflow Index (SSI) < -1.5, accumulated over 12 months.	Global
Flood magnitude	Magnitude of the 10-year return period peak flow	Global
Climate		
Annual mean and maximum temperatures	Mean seasonal, annual average and maximum temperatures.	Probabilistic Regional HadGEM3
Rainfall	Mean seasonal and annual rainfall, mm.	Probabilistic
Sea Level Rise		
Sea level rise	Annual anomalies from the baseline (1981-2000), m	Global/CMIP5

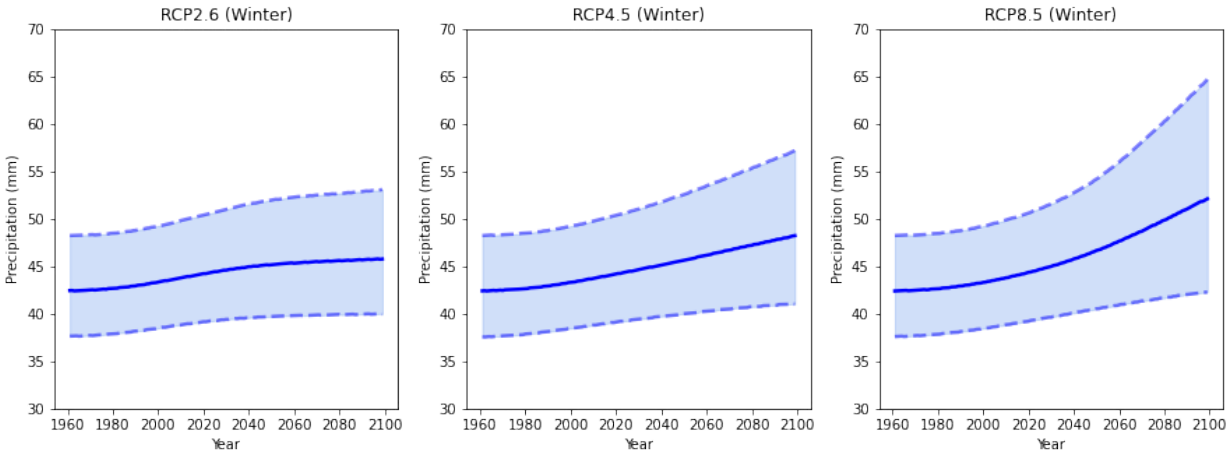
A.2.2. Future changes in temperature in Blackpool and Preston

Climate in Blackpool

Summer and winter climate in Blackpool has been analysed across three climate scenarios (RCP2.6 – low emissions, RCP4.5 – low-med emissions, and RCP8.5 – high emissions) as shown in the graphs below.

Figure A-1 Summer and winter climate scenarios for Blackpool, using different emissions predictions





These figure show the range of uncertainty for temperature and precipitation (median shown by solid lines in both summer and winter scenarios, with 5th and 95th percentiles shown by dotted lines).

As demonstrated, until the 2050s the difference between low, middle and high emission scenarios is less distinct. However, after the 2050s, the changes are significantly more visible with higher emissions scenarios.

Climate in Preston

Using the BBC and Met Office tool[83] for a snapshot of climate conditions yields the following key findings for Preston:

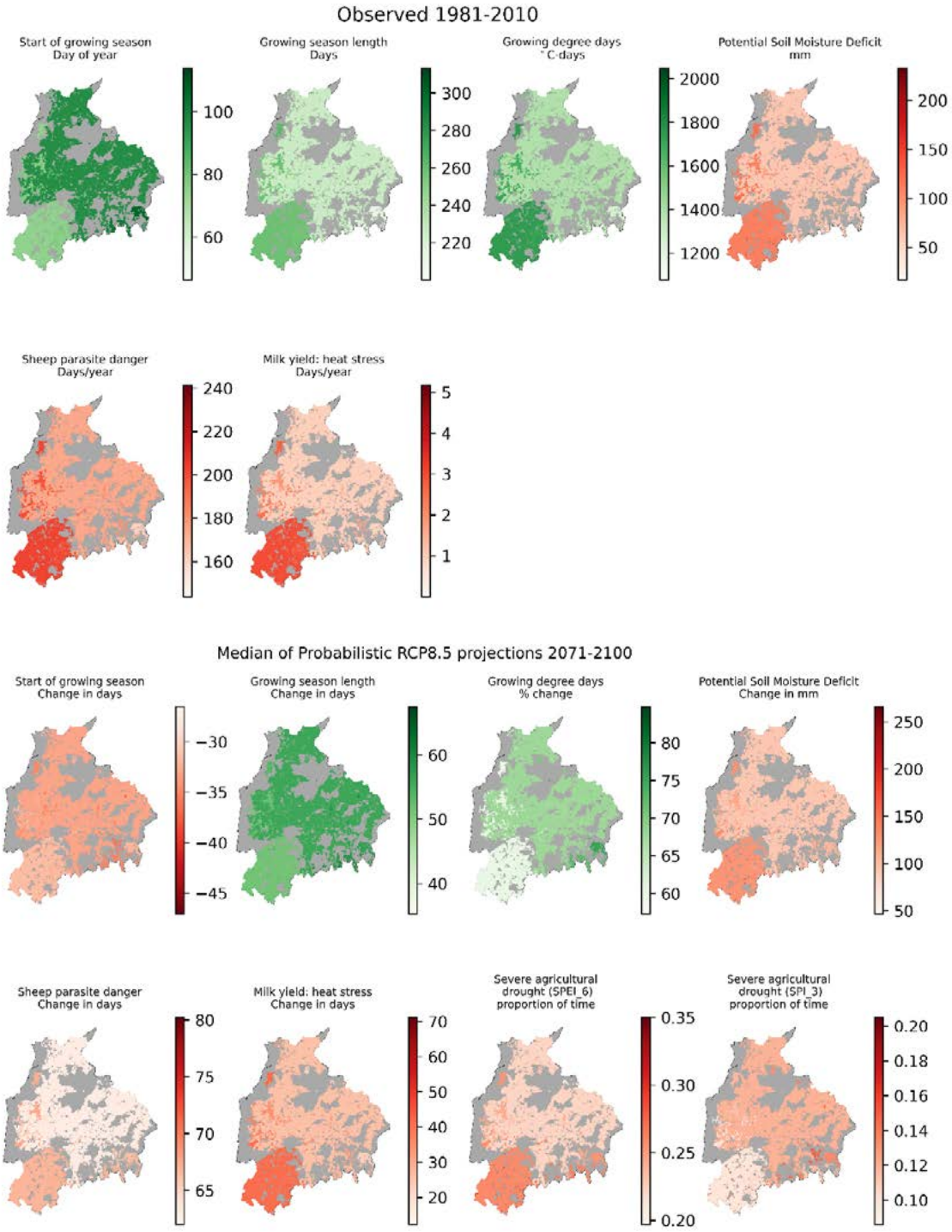
- The hottest summer day of the past 30 years was 31.9°C. If global average temperatures increase 2°C above pre-industrial levels, the hottest summer day could be about 33.6°C. If global temperatures rise by 4°C, it could be about 37.8°C.
- In the past 30 summers, there was 1 day above 25°C per month on average. If global temperatures rise by 2°C, there could be 3 days. With a 4°C global temperature rise, there could be 7 days.
- In the past 30 years, there were 12 rainy days on average per month in summer. If global average temperatures rise by 2°C, this could be 12 days per month. At 4°C global temperature rise there could be about 9 days.
- On the wettest summer day of the past 30 years, 50mm of rain fell in Preston. At a 2°C rise, this could result in about 53mm. And at a 4°C rise, there could be about 55mm, which is 9% more than now.

The present-day data is based on averages of observed measurements for 1991-2019. The future data is based on projected temperature and rainfall measurements produced by climate models for two different levels of global warming: if global average temperatures rise 2°C or 4°C above records from the pre-industrial period (mid-19th Century).

[83] What will climate change look like in your area? - BBC News

A.2.3. Baseline and future agroclimatic indicator maps

Figure A.3. Variation of agro-climate indicators across Lancashire agricultural land with high (RCP8.5) emissions. Median of Probabilistic projections. The maps show the 30-year mean.



Top: The reference period (1981-2010). Bottom: The change from the reference period.

Source: Figure 6, Arnell & Freeman, 2021 (Agro-climate paper). Agricultural area - The CORINE Land Cover (CLC) 2018.

Appendix B. Adaptative Capacity assessment framework

Adaptive Capacity	Very Low Very little progress and reacting late to the climate emergency	Low Some progress and started the journey to increased climate resilience	Medium Good progress to climate resilience with developing strategy	High Leading organisation (in sector) that understand risks and has a implemented a clear strategy and processes for climate resilience	Very High Leading organisation, fully disclosed and advanced climate risk management systems
Awareness	Climate scepticism Very low awareness of climate change limited to sustainability teams	Some awareness of climate change across the organisation. Not seen as an important part of the organisation's role.	Aware of climate change, including local impacts and how it affects the organisation.	High awareness of climate change, risks and actions taken to manage risks in the organisation.	Acutely aware of risks, including costs of inaction. Knowledge of links between risks, adaptation and economic strategy .
Agency	No formal climate change action policies	Organisation policies make reference to climate change Low uptake of climate risk information and tools Lacking strategy and no climate emergency declared	Climate change emergency declared Skilled staff and resources to support "race to resilience" Actions plans under development	High level CEO commitment Climate change emergency strategy developed and actively implemented across the organisation. Actions plans in place.	Full disclosure Funded adaptation plan Climate mainstreamed in Regional Economic Strategy Innovation in climate resilience projects
Collaboration	Internally focused with very low collaboration with outside organisations and customers.	Some collaboration, minimum requirements to meet service levels.	Reasonable collaboration on climate change including with emergency services and EA	Focused on customer needs Works with a range of interdependent public/private organisations on climate change	Leading collaboration across the region on climate change; working with the public and private sector on climate risks and adaptation.
Operations	Limited contingency planning for extreme weather No consideration of long term climate change	Some contingency planning Climate considered where mandatory only. Statutory requirements followed but not adopting best practice.	Flood/Heatwave/Cold Alerts and Plans Use of selected weather and climate data or products Projects screened for climate risks.	Use of specialist weather services Use of future flood maps and other climate information services Allowances for climate incorporated in design	Using bespoke weather services Enhancing project value, identification of adaptation opportunities Transformative projects
Learning	No review or learning from weather events	Some reflection on process and procedures related to climate risks.	Weather and climate risks are reviewed as part of some organisational procedures	Periodic monitoring and evaluation of weather and climate risks and climate change strategy and progress	Established learning processes reviewing climate risks and adaptation outcomes Annual review of Climate Action KPIs

Lancashire

Independent Economic Review

The Lancashire Independent Economic Review (IER) is led and funded by Lancashire County Council, Blackburn with Darwen Borough Council, Blackpool Council and the Lancashire Enterprise Partnership on behalf of Lancashire Leaders. Lancashire Leaders comprises the leaders of Blackburn with Darwen Borough Council, Blackpool Council, Burnley Borough Council, Chorley Borough Council, Fylde Borough Council, Hyndburn Borough Council, Lancashire County Council, Lancaster City Council, Pendle Borough Council, Preston City Council, Ribble Valley Borough Council, Rossendale Borough Council, South Ribble Borough Council, West Lancashire Borough Council, Wyre Borough Council and the Lancashire Enterprise Partnership.

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