UK Climate Risk
Independent Assessment (CCRA4)

Technical Report

Chapter 6: Infrastructure

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6.1 Chapter summary

Infrastructure – including energy, communications networks, transport, and water systems – is fundamental to the functioning of UK society and its economy. Extreme weather and long-term climate change can cause damage to infrastructure or alter the surrounding environment. This can disrupt services, reduce reliability or quality of services, and increase maintenance needs. Our infrastructure systems are interconnected and depend on each other to operate successfully. A failure in one system can impact other systems, or broader socioeconomic activities. For example, transport networks rely upon communications networks to function. This chapter considers the risks to the UK infrastructure sector from climate change.

Headlines

- Climate change is already affecting the UK. Extreme weather (high winds, high temperatures, heavy rainfall) and associated hazards (flooding, treefall, wildfires) have costly impacts on infrastructure networks and the societal and economic functions they underpin.
- Critical action is required to address risks to the delivery of infrastructure services from interdependencies with other infrastructure systems (I1). This is driven by the High-risk magnitude of many sectors and the interdependency with energy (I2, I3, I4) and digital and communication systems (I8).
- Major drivers of these risks are the intensification of extreme weather events and associated hazards, such as extreme temperatures, heavy rain and flooding, storms, and wildfires. In sectors like road, rail, and water/wastewater (I5, I6, I9), the condition and design of long-life infrastructure assets also play a major role.
- Net Zero is changing the way in which infrastructure is both exposed to, and vulnerable to, climate change (I2, I3, I4, I5). It will provide opportunities to build in climate resilience through the design and development of new infrastructure.
- Significant evidence gaps include infrastructure impacts for future climate scenarios, data demonstrating the effectiveness of adaptation measures, the impact of climate on new Net Zero infrastructure, and understanding risk at the level of individual nations.

The urgency score for Risks from interdependencies with other infrastructure systems (I1) is assessed as Critical Action Needed (the highest urgency score). This urgency score is reached in the 2050s when the risk magnitude rises to Very High (Medium confidence) for all nations. There is expected to be very large and frequent damage, with very large extent or very high pervasiveness. This brings irreversible loss of system functionality and systemic risk, costing billions annually. The risk magnitude is driven by High magnitude risks within individual infrastructure systems and compounded by high levels of interconnectedness between systems. This is particularly true for the electricity system (I2, I3, I4 and I3) and digital and communication systems (I8), which increases the potential for cascade failures across systems.

Risks with an urgency score of Critical Investigation (the second highest urgency score) include: Risks to fuel supply infrastructure (I4); Risks to road transport systems (I5); Risks to aviation, shipping, and other transport systems (I7); and Risk to electricity transmission and distribution systems in Northern Ireland (I3). These urgency scores occur at different time horizons for different risks and nations.

Across the sector, increase in risk is driven by: future intensification of climate-related hazards such as higher temperature, flooding (fluvial, pluvial, coastal), wildfires, higher sea levels and erosion; and infrastructure condition and design in some sectors such as transport and water and wastewater (I5, I6, I9). Many long-life infrastructure systems such as roads, railways, and sewage systems were not designed for the present climate, or for future climates. For some risks, e.g., water supply and wastewater (I9), failure to build resilience will have public health consequences.

Infrastructure failure and disruption has the greatest impacts on communities with the fewest resources to cope with disruptions, such as emergency reserves, suitable housing and flexible employment or transportation**.**

Net Zero is changing the infrastructure landscape particularly for electricity generation (I2), electricity transmission and distribution (I3), fuel supply (I4), and road transport (I5). This will change the exposure and vulnerability of infrastructure systems compared to the present day. It also provides opportunities to build in climate resilience through the design and development of new infrastructure.

Adaptation Reporting Power (ARP) reports and observed weather impacts are key sources of evidence for the infrastructure sector. There has been some sector specific modelling that provides information about future climate impacts for the infrastructure sector, such as the work done in the Climate Services for a Net Zero World programme (CS-N0W) for electricity generation, transmission and distribution, and fuel supply systems (I2, I3, I4). However, evidence of impacts on infrastructure in future climate scenarios is generally either limited (e.g., one scenario, one time horizon) or does not exist for different time periods, climate scenarios, or sectors.

Adaptation plans and policies exist for most sectors. Adaptation actions are starting to take place but are not on the scale required to deliver climate-resilient infrastructure systems. Some sectors (e.g., electricity generation, I2, electricity transmission and distribution, I3, rail, I6, water and wastewater, I9) are more advanced in terms of adaptation plans and policy. There is less evidence of adaptation action and progress in Northern Ireland for all sectors. Evidence of the effectiveness of adaptation actions is currently limited because there has been insufficient time for adaptation actions to deliver a benefit, there are limited monitoring and evaluation processes in place and/or adaptation actions are insufficient.

Table 6.1: List of risks and urgency scores for Infrastructure by country. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter. Where insufficient evidence is available to provide urgency scores at an individual country level, a single score is provided at the UK level in a merged box.

ID	Risk		Present	2030	2050	2080	Urgency
I1	Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems	**UK**	+++ (H)	+++ (H)	++ (VH)	+ (VH)	CAN
		England	+++ (H)	+++ (H)	++ (VH)	+ (VH)	CAN
		Northern Ireland	+++ (H)	+++a (H)	++ (VH)	+ (VH)	CAN
		Scotland	+++ (H)	+++ (H)	++ (VH)	+ (VH)	CAN
		Wales	+++ (H)	+++ (H)	++ (VH)	+ (VH)	CAN
I2		**UK**	++ (M)	++ (M)	+ (M)	+ (M)	MAN

	Risks to electricity generation	England	++ (M)	++ (M)	+ (M)	+ (M)	MAN
		Northern Ireland	++ (M)	+ (M)	+ (M)	+ (M)	MAN
		Scotland	++ (M)	++ (M)	+ (M)	+ (M)	MAN
		Wales	++ (M)	++ (M)	+ (M)	+ (M)	MAN
I3	Risks to electricity transmission and distribution systems	**UK**	+++ (H)	+ (H)	+ (H)	+ (H)	CI
		England	+++ (H)	+++ (H)	++ (H)	++ (H)	MAN
		Northern Ireland	+++ (H)	+ (H)	+ (H)	+ (H)	CI
		Scotland	+++ (H)	+++ (H)	++ (H)	++ (H)	MAN
		Wales	+++ (H)	+++ (H)	++ (H)	++ (H)	MAN
I4	Risk to fuel supply systems	**UK**	+ (H)	+ (H)	+ (H)	+ (H)	CI
		England	++ (H)	++ (H)	+ (H)	+ (H)	CI
		Northern Ireland	+ (H)	+ (H)	+ (H)	+ (H)	CI
		Scotland	++ (H)	++ (H)	+ (H)	+ (H)	CI
		Wales	++ (H)	++ (H)	+ (H)	+ (H)	CI
I5	Risks to road transport systems	**UK**	++ (H)	++ (H)	+ (H)	+ (VH)	CI
		England	++ (H)	++ (H)	+ (H)	+ (VH)	CI
		Northern Ireland	++ (H)	++ (H)	+ (H)	+ (VH)	CI
		Scotland	++ (H)	++ (H)	+ (H)	+ (VH)	CI
		Wales	++ (H)	++ (H)	+ (H)	+ (VH)	CI
I6	Risk to rail transport systems	**UK**	++ (H)	++ (H)	++ (H)	++ (VH)	MAN
		England	++ (H)	++ (H)	++ (H)	++ (VH)	MAN
		Northern Ireland	++ (M)	++ (M)	++ (M)	++ (H)	MAN
		Scotland	++ (M)	++ (M)	++ (H)	++ (H)	MAN
		Wales	++ (M)	++ (M)	++ (M)	++ (H)	MAN

I7	Risks to aviation, shipping, and other transport systems	**UK**	+ (H)	+ (H)	+ (H)	+ (H)	CI
		England	+++ (H)	++ (H)	+ (H)	+ (H)	CI
		Northern Ireland	+ (H)	+ (H)	+ (H)	+ (H)	CI
		Scotland	+++ (H)	+ (H)	+ (H)	+ (H)	CI
		Wales	+ (H)	+ (H)	+ (H)	+ (H)	CI
I8	Risks to digital and communications systems	**UK**	+ (M)	+ (M)	+ (M)	+ (H)	FI
		England	+ (M)	+ (M)	+ (M)	+ (H)	FI
		Northern Ireland	+ (M)	+ (M)	+ (M)	+ (H)	FI
		Scotland	+ (M)	+ (M)	+ (M)	+ (H)	FI
		Wales	+ (M)	+ (M)	+ (M)	+ (H)	FI
I9	Risks to water supply and wastewater systems	**UK**	+++ (H)	++ (H)	++ (H)	++ (VH)	MAN
		England	+++ (H)	++ (H)	++ (H)	++ (H)	MAN
		Northern Ireland	++ (H)	++ (H)	++ (H)	++ (VH)	MAN
		Scotland	+++ (H)	++ (H)	++ (H)	++ (H)	MAN
		Wales	++ (H)	++ (H)	++ (H)	++ (H)	MAN
I10	Risks to waste management systems, excluding wastewater systems	**UK**	+ (H)	+ (M)	+ (M)	+ (M)	CI
		England	+ (L)	+ (L)	+ (L)	+ (L)	FI
		Northern Ireland	+ (L)	+ (L)	+ (L)	+ (L)	FI
		Scotland	+ (L)	+ (L)	+ (L)	+ (L)	FI
		Wales	+ (H)	+ (M)	+ (M)	+ (M)	CI

6.2 Risks to Infrastructure

6.2.1 Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems – I1

This risk considers the interdependencies between sectors, and how a failure or disruption in one system can disrupt the delivery of services within one or more infrastructure systems. For example, disruptions to electricity generation, distribution or transmission can lead to widespread impacts across multiple other sectors such as transport and digital and communications systems.

Headlines

- The risk magnitude is High for the present day and the 2030s, increasing to Very High from the 2050s onward. An urgency score of "Critical Action Needed" has been assigned based on the Very High Magnitude and Medium Confidence in the 2050s.
- The risk magnitude is driven by both the magnitude of risk within individual systems and the level of interconnectedness of infrastructure systems.
- Risk magnitude for many sectors (Sections 6.2.1 to 6.2.10) is High and increases in the future.
- There is a high level of interconnectedness between risks, particularly with electricity generation, transmission and distribution (I2, I3) and digital and communication systems (I8).
- There are very few studies that assess risk from interdependencies on specific timescales, as well as few methods or studies that monitor or evaluate adaption progress.

Table 6.2: Urgency scores for I1 Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I1	Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems	**UK**	+++ (H)	+++ (H)	++ (VH)	+ (VH)	CAN
		England	+++ (H)	+++ (H)	++ (VH)	+ (VH)	CAN
		Northern Ireland	+++ (H)	+++ (H)	++ (VH)	+ (VH)	CAN
		Scotland	+++ (H)	+++ (H)	++ (VH)	+ (VH)	CAN
		Wales	+++ (H)	+++ (H)	++ (VH)	+ (VH)	CAN

6.2.1.1 Evidence relevant to the entire United Kingdom

The climate risk for this sector is broadly UK-wide, and therefore the devolved nations will experience similar current and future drivers of risk, current and future magnitudes of risk, and levels of preparedness for risk.

Current and future drivers of risk

Infrastructure systems such as transport, energy and telecommunications are highly interconnected to other infrastructure systems and a disruption in one sector can trigger failures in others, thereby amplifying the overall impact of an initial incident. For example, a power outage can disable communication networks, disrupt water supply systems reliant on electric pumps, and halt transportation services that depend upon signal systems. These failures, in turn, can affect emergency response, healthcare delivery, and economic activities (Figure 6.2).

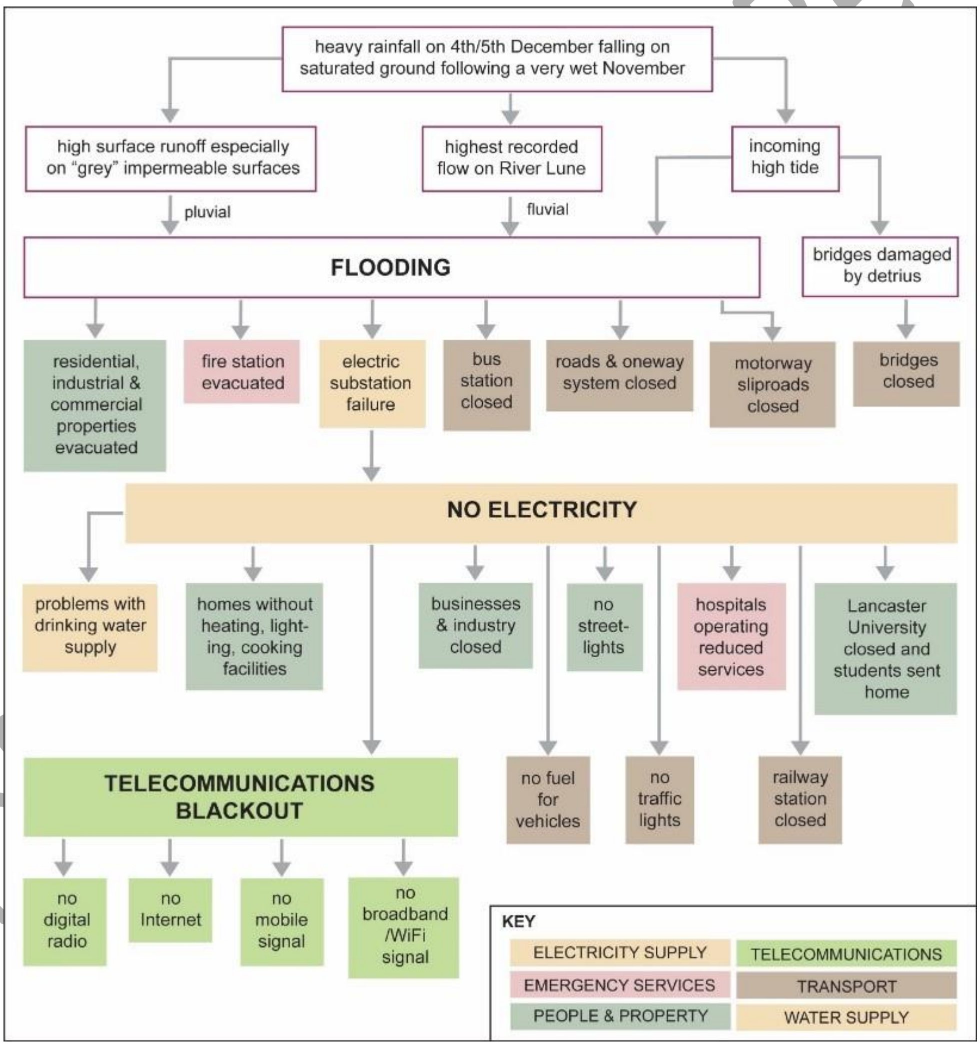

Figure 6.1. The loss of critical infrastructure systems in Lancaster following Storm Desmond, 2015 (Ferranti et al., 2017).

Several factors drive increased risk to infrastructure services from interdependencies with other infrastructure systems, ranging from climate change to deepening interdependencies between systems. Key drivers include:

- The intensification of climate change impacts. This increases the risk within individual critical infrastructure systems, particularly electricity generation (I2), energy transmission and distribution (I3) and digital and communications infrastructure (I8), as well as exacerbating the consequences from system interdependencies. More frequent and severe extreme weather events (e.g., heatwave or storms) can trigger downstream failures across interconnected networks.
- The interconnectedness of infrastructure services. Electricity generation and transmission and distribution systems (I2, I3) underpin most other infrastructure services. The increasing use of digital sensors and communications, together with AI, deepens the interdependence with the digital and communications sector (I8).
- Co-location of critical infrastructure items. This allows the same weather event to impact multiple systems, thereby amplifying the potential impact of an extreme weather event. For example, where data servers and electricity substations are co-located the same event could lead to multi-system failures. Similarly, co-located coastal infrastructure services are at risk from storm surges and flooding which can simultaneously impact port operations, electricity substations located along the coast, and adjacent wastewater facilities, having knock-on effects on supply chain distribution.
- Increasing exposure to climate risks occurring overseas due to global supply chains, digital technologies, and energy systems. Upstream disruptions to these supply chains from extreme weather overseas can affect key manufacturing hubs or transport corridors. This can create downstream impacts on the availability of critical components, fuel supplies and food distribution in the UK. These interdependent risks are often nonlinear, rapidly escalating, and difficult to predict or contain.

Assessment of current magnitude of risk

The current magnitude of this risk is assessed as High with High Confidence given the many observed examples of infrastructure interdependencies causing major damage and disruption or foregone opportunities. These include the loss of all critical infrastructure systems to Lancaster following Storm Desmond in 2015, a data centre outage causing loss of operations to Guy's and St. Thomas's NHS Trust following the heatwave in July 2022 (see I8 digital and communications systems, and NHS (2023)), and a loss of energy generation following a likely lightning strike to an overhead transmission line north of London in August 2019, leading to major disruption on the railway network, including blocked lines out of Farringdon and King's Cross stations along with wider cancellations and significant delays impacting thousands of passengers (ORR, 2020; NESO, 2019).

Assessment of future magnitude of risk

The future magnitude of risk is determined by the magnitude of risk within individual infrastructure systems, particularly electricity supply and distribution, and their level of interconnectedness. Evidence from the majority of infrastructure sector risks indicate these factors remain High, or increase in the future, and an economic study indicates the risk from interdependencies could cost billions per year in the 2050s (Watkiss, 2022).

<u>2030s, central warming scenario:</u>

In the near future there may be some amplification of climate hazards (based on rapid climatic changes observed in the past decade) and changes to the infrastructure landscape, including increasing interdependence with digital and communication systems (I8). It is likely that the magnitude of risk will increase but will remain in the High magnitude banding. The Net Zero transition will begin to change the infrastructure assets associated with electricity generation, fuel supply, and electricity distribution and transmission. This new infrastructure may present an opportunity to build-in increased resilience. Thus, expert judgment considers the magnitude of risk in the 2030s to be similar to present day with High Confidence.

<u>2050s, central and high warming scenarios:</u>

By the 2050s, climate change impacts will have significantly intensified, greatly increasing the magnitude of risks from extreme weather events. Infrastructure systems are expected to be increasingly interconnected, particularly with energy generation, transmission and distribution (I2, I3), and digital and communication systems (I8), thereby increasing the potential for impacts. Infrastructure systems are likely to have changed significantly as the UK transitions to Net Zero.

The short life of many communications technologies means many current day assets are likely to have been replaced. However, some infrastructure assets associated predominantly with fuel supply and transport services have much longer lifetimes where risks from climate change are likely to increase.

An economic study indicates the risks from infrastructure interdependencies could reach billions per year by 2050s (Watkiss, 2022). Risk magnitude therefore rises to Very High, but the single source of evidence combined with expert judgment reduce the confidence to Medium.

<u>2080s, central and high warming scenarios:</u>

By the 2080s, climate change impacts continue to intensify, further increasing the magnitude of risk. Infrastructure systems are likely to have changed significantly as technology advances. There is no specific evidence for this time period; expert judgment considers the magnitude of risk to remain Very High, but the confidence level to be Low.

Level of preparedness for risk

The CCC (2023a) has identified the lack of systematic national assessment of interdependency risks, while the NIC (National Infrastructure Commission, now the National Infrastructure and Service Transformation Authority, NISTA) recommended in 2022 and 2024 that “regulators […] put in place a system for cross-sector stress testing, which addresses interdependencies and the risk of cascade failures”, and highlighted the need to include climate change in traditional hazard analysis, and the role for the Cabinet Office in coordinating effort across Government (NIC, 2022; NIC, 2024).

Several infrastructure bodies exist (partly identified in the Civil Contingencies Act (2004)) which could facilitate improved cross-sector coordination on climate change interdependencies:

- Infrastructure Operators Adaptation Forum
- Local Resilience Forums (England and Wales)
- Cabinet Office-led Infrastructure, Resilience and Security Working Group
- National Infrastructure and Service Transformation Authority (NISTA)

The Department for Transport is, at the time of writing, scoping work to support transport stakeholders in furthering their understanding of risks arising from interdependencies.

Assessment of the evidence base and evidence gaps

More research is urgently needed on the current level of risks to key interconnected infrastructure networks. While the impacts of extreme weather events on transport and energy sectors are somewhat understood, more research is required to understand the downstream impacts into other infrastructure services.

At present, there is no means to monitor and evaluate progress in managing the risks from interdependencies via the ARP process; ARP reports are submitted by organisations, and no organisation oversees adaptation progress or mandates adaptation actions. There is also a lack of sight of cross-Government collaboration on systematic national assessment of interdependency risk (CCC, 2025a), as well as an urgent requirement to understand the downstream impacts of sector-specific adaptation strategies on interconnected infrastructure systems.

6.2.1.2 England

Key climatic considerations in England that influence risks from interdependencies with other infrastructure systems are high temperatures and heatwaves, droughts, high winds, storms, and flooding (fluvial, pluvial, and coastal).

The congested nature of London's infrastructure produces a total of 114 potential cascading risks to the transport system in the present-day, 2050s, and 2080s (TfL, 2024a). For example, significant risks to power substations from both high temperatures and flooding, particularly during periods of high demand, can have downstream impacts on power supply for critical operations linked to rail infrastructure (e.g., track, signage) and road networks (e.g., street lighting). By the 2050s, increases in winter rainfall (State of the Climate Chapter) will lead to increased pluvial and fluvial flooding which in turn can damage civil, water, and transport structures.

The southeast of England is most at risk from drought (State of the Climate Chapter), which could disrupt interconnected infrastructure services that rely on water for cooling (I9) such as (i) thermal power plants, (ii) electricity substations for transmission, and (iii) data centres for cooling systems. By the 2050s, summers will be hotter and drier (State of the Climate Chapter) which will lead to increased length and severity of heatwaves and droughts, which in turn can impact water resources, transport structures and digital services.

As reported in risks to digital and communications systems (I8), 80% of data centres are clustered centrally around the M25 and adjacent to existing fibre optic and power infrastructure. Therefore, a single extreme weather event (e.g., heatwave or storm) could result in the shutdown of multiple data centres simultaneously. This could disrupt interconnected infrastructure services causing (i) power grid instabilities, (ii) impacts on transport and water systems, and (iii) widespread telecommunication networks failures.

Evaluation of urgency score

Risk magnitude is considered High for present day and for 2030s, with High Confidence given the observed examples of infrastructure interdependencies causing major damage and disruption or foregone opportunities on the scale of millions per year. If these increase in the near future, impacts will remain in High magnitude banding. For 2050s onwards, risks from infrastructure interdependencies could reach billions per year (Watkiss, 2022); Confidence is Medium for 2050s but reduces to Low for 2080s where scoring is based solely on expert judgment. Many ARP4 reports now consider upstream and downstream interdependencies as part of their reporting process; however, plans and policies remain limited (CCC, 2023a), thus there are no changes to Risk magnitude after considering adaptation.

Table 6.3: Urgency scores for I1 Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England

I1	Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	+++ (H)	+++ (H)	++ (VH)	++ (VH)	+ (VH)	+ (VH)	+ (VH)
With adaptation	+++ (H)	+++ (H)	+++ (H)	++ (VH)	++ (VH)	+ (VH)	+ (VH)	+ (VH)
Urgency scores	MAN	MAN		CAN			FI	
Overall urgency score	CAN							

6.2.1.3 Northern Ireland

The specific climatic consideration in Northern Ireland that influences risks to the delivery of infrastructure services from interdependencies with other infrastructure systems is storms, particularly those producing high winds and flooding. For example, the local road network within Northern Ireland is at high risk of flooding due to both extreme rainfall events and the overall poor condition of the roads (CCC, 2023b). Should this lead to road closures during a storm event, there could be knock-on consequences for access or maintenance of other systems. Electricity generation and transmission are part of the Irish Grid, thus there are international interdependencies, and under a different regulatory framework than Great Britain.

Evaluation of urgency score

Risk is considered High for present day and for 2030s, with High Confidence given the observed examples of infrastructure interdependencies causing major damage and disruption, or foregone opportunities on the scale of millions per year; if these increase in the near future, impacts will remain in High magnitude banding. For 2050s onwards, risks from infrastructure interdependencies could reach billions per year (Watkiss, 2022). Confidence is Medium for 2050s but reduces to Low for 2080s where scoring is based solely on expert judgment. These reports now consider upstream and downstream interdependencies as part of their reporting process, however plans and policies remain limited (CCC, 2023a). Thus, there are no changes to Risk magnitude after considering adaptation.

Table 6.4: Urgency scores for I1 Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland

I1	Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	+++ (H)	+++ (H)	++ (VH)	++ (VH)	+ (VH)	+ (VH)	+ (VH)
With adaptation	+++ (H)	+++ (H)	+++ (H)	++ (VH)	++ (VH)	+ (VH)	+ (VH)	+ (VH)
Urgency scores	MAN	MAN		CAN			FI	
Overall urgency score	CAN							

6.2.1.4 Scotland

The specific climatic considerations in Scotland that influence risks to the delivery of infrastructure services from interdependencies with other infrastructure systems are extremes in precipitation, strong winds, erosion and drought.

As reported in risks to rail (I6) and digital and communications systems (I8), winter storms can have a significant impact on rail transportation services and digital and communications services. For example, in 2022, Storms Dudley, Eunice, and Franklin occurred in the same week in February (Met Office, 2022a). This resulted in widespread disruption and cancellations to railway services across the country, including a tree that caught fire when it fell onto overhead lines (Network Rail, 2022). When train services are delayed or suspended it can lead to an increase in pressure on other modes of transportation (e.g., buses and taxis), although these may also be impacted by the same storm. Similarly, Storm Arwen impacted Scotland in November 2021 and Storm Éowyn in January 2025, leading to downstream impacts on phone and broadband connections. Broadband services failure can lead to multi-sector disruption, with reports in the media that these lead to impacts on (i) transport, due to the loss of communication between drivers and the control centre, and (ii) real-time monitoring and control of water treatment works and / or power grids.

As reported in risks to water and wastewater (I9), a small but substantial part of the Scottish population (3.6%) rely on private water supplies. Currently Scotland experiences a drought event every 20 years, although by 2040 this is likely to occur every 3 years (Visser-Quinn et al., 2021). Given that the River Spey and the River Tay are both susceptible to drought and abstraction, this will increase pressure on water supplies (Visser-Quinn et al., 2021). Drought and abstraction could impact buried infrastructure (e.g., I4), while insufficient supply may impact sectors that require water for cooling (e.g., I2), irrigation or processing.

Evaluation of urgency score

Risk is considered High for present day and for 2030s, with High Confidence given the observed examples of infrastructure interdependencies causing major damage and disruption, or foregone opportunities, on the scale of millions per year; if these increase in the near future, impacts will remain in High magnitude banding. For 2050s onwards, risks from infrastructure interdependencies could reach billions per year (Watkiss, 2022);

Confidence is Medium for 2050s but reduces to Low for 2080s where scoring is based solely on expert judgment. Many ARP4 reports now consider upstream and downstream interdependencies as part of their reporting process, however, plans and policies remain limited (CCC, 2023a). Thus, there are no changes to Risk magnitude after considering adaptation.

Table 6.5: Urgency scores for I1 Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland								
I1 Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems.								
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	+++ (H)	+++ (H)	++ (VH)	++ (VH)	+ (VH)	+ (VH)	+ (VH)
With adaptation	+++ (H)	+++ (H)	+++ (H)	++ (VH)	++ (VH)	+ (VH)	+ (VH)	+ (VH)
Urgency scores	MAN	MAN		CAN			FI	
Overall urgency score	CAN							

6.2.1.5 Wales

The specific climatic considerations in Wales that influence risks to the delivery of infrastructure services from interdependencies with other infrastructure systems are flooding, high winds, erosion, and high temperatures.

As reported in risks to rail (I6), storms Dudley, Eunice, and Franklin occurred in one week in February 2022 and resulted in major transport disruption in Wales, with some Wales & Western railway services stopped, and Network Rail suspending all services (Met Office, 2022a; Network Rail, 2022). When train services are delayed or suspended, it can increase pressure on other modes of transportation (e.g., buses and taxis), though these are likely also impacted by the same storm. For example, heavy precipitation from winter storms can cause flooding. As reported in risks to road transport systems (I5), flooding and associated landslips are the primary drivers for road maintenance and renewal. Coastal road schemes specifically have a growing risk of coastal erosion under climate change (GOV Wales, 2023). When roads and rail are closed due to flooding, it can have widespread downstream impacts on other infrastructure services. This can include delays to engineers responding to substation failures or breakages, or preventing deliveries of fuel to substations or backup generators and chemicals to water and wastewater treatment sites.

Evaluation of urgency score

Risk is considered High for present day and for 2030s, with High Confidence given the observed examples of infrastructure interdependencies causing major damage and disruption, or foregone opportunities on the scale of millions per year. If these increase in the near future, impacts will remain in High magnitude banding. For 2050s onwards, risks from infrastructure interdependencies could reach billions per year (Watkiss, 2022); Confidence is Medium for 2050s but reduces to Low for 2080s where scoring is based solely on expert judgment. Many ARP4 reports now consider upstream and downstream interdependencies as part of their reporting process; however, plans and policies remain limited (CCC, 2023a). Thus, there are no changes to Risk magnitude after considering adaptation.

Table 6: Urgency scores for I1 Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales								
I1	Risks to the delivery of infrastructure services from interdependencies with other infrastructure systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	+++ (H)	+++ (H)	++ (VH)	++ (VH)	+ (VH)	+ (VH)	+ (VH)
With adaptation	+++ (H)	+++ (H)	+++ (H)	++ (VH)	++ (VH)	+ (VH)	+ (VH)	+ (VH)
Urgency scores	MAN	MAN		CAN			FI	
Overall urgency score	CAN							

6.2.2 Risks to electricity generation – I2

This risk covers the diverse mix of electricity generation assets including nuclear, fossil fuels, renewables and storage, as well as the associated security of supply. Electricity generation in England, Scotland and Wales is part of the GB energy market whereas generation in Northern Ireland is part of the Single Electricity Market for the island of Ireland.

Headlines

- Risks to electricity generation have been assessed as More Action Needed to reflect the Medium Magnitude and Confidence in climate risks.
- Future changes in risk are driven by (i) increased exposure due to an increase in the number of weather-dependant assets, (ii) the diversification of the type and location of generation assets which inherently increases redundancy, and (iii) future changes in the balance between supply and demand, which is proactively managed by security of supply assessments.
- It remains a priority to address evidence gaps around quantifying the risks and associated adaptation required for specific electricity generation assets.
- Despite extensive analysis of future changes to electricity generation and associated hazards, metrics to evaluate the effectiveness of future adaptation and evidence quantifying the risk magnitude are lacking.

Table 6.7: Urgency scores for I2 Risks to electricity generation. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I2	Risks to electricity generation	**UK**	++ (M)	++ (M)	+ (M)	+ (M)	MAN
		England	++ (M)	++ (M)	+ (M)	+ (M)	MAN
		Northern Ireland	++ (M)	+ (M)	+ (M)	+ (M)	MAN
		Scotland	++ (M)	++ (M)	+ (M)	+ (M)	MAN
		Wales	++ (M)	++ (M)	+ (M)	+ (M)	MAN

6.2.2.1 Evidence relevant to the entire United Kingdom

Current and future drivers of risk

The electricity generation mix of the UK as depicted in Figure 6.3 has continued to evolve over the last five years, including shutdown of the UK's last coal-fired generation station in 2024.

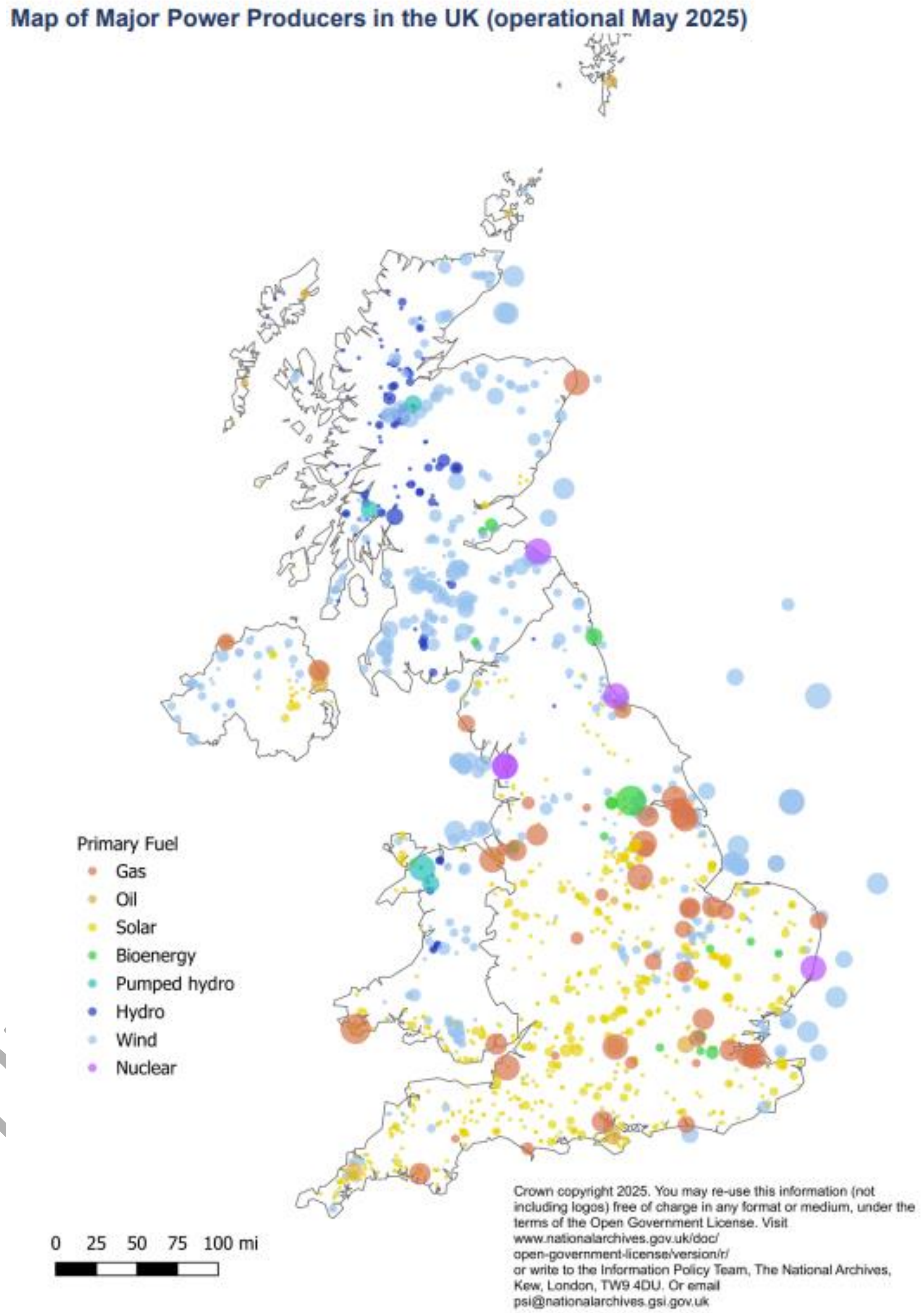

Figure 6.2. Map of Major Power Producers in the UK (operational May 2025) Source: DESNZ, 2025b

In 2024, electricity generation in the UK was produced via renewables (50.4%), fossil fuels (31.8%), nuclear (14.2%) and other fuels and storage. The share from renewables increased from 36.6% in 2019 (DESNZ, 2025a). The growth of renewable generation continues, having increased tenfold since 2000 (DESNZ, 2025b). From 2019 to 2024, in the UK, the capacity of renewable generation grew from 47 GW to 60.6 GW (DESNZ, 2025c) and the total generation capacity grew from 103.1 GW to 105.4 GW (DESNZ, 2025d).

Meeting the 2030 Clean Power targets will require substantial addition of offshore wind, onshore wind, and solar generation alongside a range of technologies. These include low carbon dispatchable generation and storage for periods of lower renewable generation (NESO, 2024a). According to the National Energy System Operator (NESO), Wind and Solar could make up 80-84% of Great Britain's 2030 supply (NESO, 2024a). In 2030, most gas generation is anticipated to remain on the system to maintain security of supply (NESO, 2024a), but unabated gas generation will increasingly need to be replaced by gas with CCS or hydrogen-fired turbines. The CCC seventh carbon budget Balanced Pathway phases out unabated gas capacity by 2050 (CCC, 2025b). By 2050, the CCC projects further growth in renewable generation with capacity projections of 125 GW for offshore wind, 37 GW for onshore wind, and 106 GW for solar PV (CCC, 2025b). However, asset owners report newer generation assets have climate risk built into their design (EUK, RUK, and SEUK, 2025). There is also expected to be at least a doubling of electricity demand as other sectors like heating and transport decarbonise, placing further reliance on electricity generation (CCC, 2025b). This increases the wider societal consequences of loss of power across health (H1), the built environment (BE7, BE8), and the economy (E1). The magnitude of risk in these downstream sectors would be above and beyond what is presented in this section (I2).

With supply increasingly dependent on wind and solar, demand becoming more sensitive to changes in temperature, and correlated weather patterns across Europe potentially limiting import capacity during prolonged periods of low wind and low temperatures, weather is expected to become the dominant driver of risk to resource adequacy in a decarbonised power system (NESO, 2025a; Lücke et al., 2024). Increasing decentralisation can reduce the exposure to loss of a single asset but may introduce new failure modes due to lack of visibility and control. The growth in offshore wind also places a higher reliance on undersea cables and offshore infrastructure and there is more limited data about historical asset performance.

Risks to electricity generation are made up of two key components, risks of damage to electricity generation assets themselves, and risks to security of supply posed by changes in generation output. The hazards and impacts are summarised in Table 6.8.

Table 6.8: Summary of the range of weather hazards that impact electricity generation. Information from (EUK, RUK, and SEUK, 2025) and (Energy UK, 2021) except where otherwise stated.

Hazard	**Impact**
Heat	High temperatures can reduce generation efficiency of thermal and solar plants, accelerate component wear, reduce cooling efficiency, and increase the probability of unexpected outages (McGuire, et al., 2025; Saxena, et al., 2024).
Drought	Lack of precipitation and drought can limit output from hydropower generation, and access to water for cooling.
Cold	Colder temperatures can cause icing, disruption to site access or other operational limitations including constraints in performance.

Excessive Rainfall and Flooding	Flooding can cause damage to generation facilities, limit access, and associated debris can block water intake. With gas and nuclear generation located along the coast, erosion and coastal flooding worsened by sea level rise also pose a long-term threat to facilities. However, for nuclear assets, there are plans to mitigate all risks with a 1-in-10,000 year return period (i.e. a 0.01% per year probability of occurrence). Sea level rise can also impact the structural integrity of structures or cables associated with offshore wind (Juhola et al., 2024).
Storms and Wind	Storms can lead to asset damage, with extreme winds causing shutdown of wind turbines, waves adversely affecting offshore infrastructure. Periods of low wind reduce electricity generation (Kapica et al., 2024; Kay et al., 2023; Wilczak et al., 2025).

Assessment of current magnitude of risk

Currently there is a Medium risk from climate change, determined from multiple sources of evidence including sector level adaptation plans and strategies. The more limited evidence for impact quantification, particularly impact to assets, results in a Medium confidence, indicating an urgency score of More Action Needed.

For risks to assets, ARP4 surveys indicated the largest number of responses for high and low temperatures, high winds and lightning (EUK, RUK, and SEUK, 2025). While magnitude was not quantified for these areas, one respondent had already experienced impacts from inability to discharge cooling water due to high temperatures, and similar experiences have been seen throughout Europe during the 2025 heatwave (Czyzak et al., 2025). ARP4 surveys also indicated widespread flood risk across generation technologies (EUK, RUK, and SEUK, 2025). Sayers et al. (2020) quantified the number of power stations exposed to significant risk from flooding (surface water, fluvial and coastal) in the 2020s and for future scenarios. Overall, for risks to generation assets, quantitative evidence is limited as electricity generators are not required to submit climate resilience strategies to Ofgem and voluntarily submitted ARP reports are provided at a sector level (CCC, 2025a).

Maintaining adequate security of supply is not a new issue, and electricity generation has demonstrated resilience to recent weather-related hazards. When considering the security of supply in current climate, the NESO 2024/25 winter outlook indicated a Loss of Load Expectation – “the [mean] number of hours when demand is higher than available generation during the year” – of 0.1 hours/year which is well below the 3-hour limit in the Reliability Standard (NESO, 2024b). Great Britain has shared electricity markets which couples the operational impacts of generation shortfall across nations (NESO, 2025b). Overall, this diversification reduces the overall risk of loss of individual facilities but can create other challenges during more widespread regional events such as the heat and drought across Europe in 2022 (RTE, 2023). Though in a separate Single Electricity Market, Northern Ireland is also interconnected with Great Britain and is dependent on GB for energy security (UK Parliament, 2018). The National Energy Systems Operator (NESO) in Great Britain and System Operator for Northern Ireland (SONI) manage their respective systems to maintain security of supply, accounting for unexpected breakdown or loss of generation facilities (NESO, 2024b; SONI, 2024). As a result, there are limited recent examples of generation failure leading to widespread power outages (Energy UK, 2021; EUK, RUK, and SEUK, 2025). Robust economic evaluations of the associated impacts remain limited; however, widespread or long-lasting shortfalls of supply at Great Britain level inevitably have large impacts across many sectors and impacts could vary significantly based on location.

Assessment of future magnitude of risk

Extreme weather and other climate hazards (e.g., flooding) will increase in frequency and magnitude in the future. However, evidence quantifying the magnitude of impacts to UK electricity generation, particularly assets, remains limited. Across hazards, asset owners report new plants have climate risk built into asset design, while climate risks to existing plants are mitigated by site managers through site-level policies (EUK, RUK, and SEUK, 2025). The future decarbonised power system will be more weather dependent (NESO, 2025a). Studies assessing changes to wind generation highlight the importance of spatial diversity to security of supply (Abdelaziz et al., 2024; Bloomfield, 2025). Further studies indicate potential reductions in hydropower output but find the magnitude of these changes is tightly linked to abstraction (Golgojan et al., 2024; Dallison and Patil, 2023). One estimate puts the overall national increase in water demand for the power sector in the order of 1,000 Megaliters per day (Water Resources East, 2023). Though future water abstraction needs for electricity generation remain uncertain, the sector is ‘potentially very sensitive to reduction’ as even small reductions could prevent plants from operating (Water Resources East, 2023; p.30). Increased temperatures will also reduce solar PV efficiency, becoming more important as the fleet of solar generation grows, but this can be counter-balanced by reductions in cloud cover, highlighting the uncertainty around future changes to production (Belcher et al., 2023; EUK, RUK, and SEUK, 2025; Kuriakose et al., 2025). In the progression towards 2080, models indicate an increase in the duration and severity of stress events (Bloomfield, 2025), demonstrating the need for adequate flexible supply and storage to complement weather dependent renewables (Lücke et al., 2024; NESO, 2025b). Although risk to the supply of electricity is recognised in the National Adaptation Programmes for each UK nation (CCC, 2023b; CCC, 2023c; CCC, 2023d; CCC, 2025a), there is presently little evidence of progress on asset level adaptation due to the lack of quantification.

<u>2030s, central warming scenario:</u>

From an asset perspective, under a 2 °C warming scenario and current levels of adaptation, Sayers et al. (2020) identified increases in the number of power stations exposed to significant risk from flooding. From a security of supply perspective, by 2030, renewable generation is expected to grow to 80 to 84% of GB’s power supply (NESO, 2024a) with capacity of renewable generation anticipated to more than double in the UK (CCC, 2025b). This growth drives an increase in exposure and projected increasing magnitude of short duration system stress events (Bloomfield, 2025; NESO, 2025a). The magnitude of these events is influenced by a variety of factors including spatial diversity of generation, interconnection with neighbouring countries, and asset damage (Sanchez et al., 2023; Lücke et al., 2024; Bloomfield, 2025). Despite the projected changes, it is anticipated that sufficient dispatchable generation will be present to provide backup in the event of a weather-related reduction in output (NESO, 2025a). Therefore, the magnitude of risk is kept constant between present day and 2030s.

<u>2050s, central and high warming scenarios:</u>

From an asset perspective, growth in existing power station exposure to flooding increases (Sayers et al., 2020). For security of supply, a five-fold increase in renewable generation capacity from the present is anticipated for the UK with the CCC (2025b) estimating 125 GW of offshore wind, 37 GW onshore wind, 106 GW solar PV, 38 GW of low carbon dispatchable capacity, and 35 GW (139 GWh) of battery storage. Demand is also projected to more than double from 279 TWh in 2025 to 692 TWh in 2050. Risk associated with increases in weather dependent renewables can be effectively managed through proper planning of the supply mix, including sufficient long-duration energy storage and low carbon dispatchable power (NESO, 2024a; Smith et al., 2023).

<u>2080s, central and high warming scenarios:</u>

From an asset perspective, existing power station exposure to flooding increases (Sayers et al., 2020). For security of supply, an increase in periods of low availability for solar and wind resources is projected for the UK (Kapica et al., 2024). As in previous periods, this is anticipated to be managed through adequate planning for security of supply.

Tipping points (State of the Climate Chapter) would exacerbate temperature, water, and wind-related impacts on electricity generation. Notable examples include a potential collapse in the Atlantic Meridional Overturning Circulation (AMOC) or the North Atlantic Subpolar Gyre (SPG), which play a critical role in determining UK weather patterns (Laybourn et al., 2024). Lenton et al. (2023, p. 191) indicate a potential AMOC collapse would impact energy generation due to changing wind or rainfall patterns but note that these changes have yet to be assessed.

Cascading risks are a particular concern for electricity generation, with electricity generation supply underpinning the entire economy, particularly with further demand growth and decarbonisation of heating and transport. Other interdependencies also include electricity transmission and distribution networks (I3) and fuel supply systems (I4).

Level of preparedness for risk

From an asset perspective, prior overall sector reports have indicated the perspective that near future impacts from climate change will be ‘relatively small’ compared to currently managed operational risks (Energy UK, 2021) and the latest ARP4 report indicated high industry confidence in plans to manage with future climate risks (EUK, RUK, and SEUK, 2025). Further mechanisms such as the Capacity Market also provide a pathway to manage the supply and demand balance (NESO, 2025a). Adaptation plans for electricity generation assets have been provided at a sector level via Energy UK, with coverage expanding to Renewable UK and Solar Energy UK in ARP4, capturing a wider share of the overall market (EUK, RUK, and SEUK, 2025). While these adaptation reports provide a qualitative demonstration of awareness of the risks that face the sector, they lack detailed adaptation strategies with quantitative measures of success beyond the present. This is further evidenced in CCC evaluations for each of the devolved nations for the generation sector which indicate clear gaps in data (CCC, 2023b; CCC, 2023c; CCC 2023d; CCC, 2025a). New electricity generation often requires environmental impact assessments, including climate change resilience assessment (EUK, RUK, and SEUK, 2025). However, existing reporting mechanisms and requirements for individual generators may not align with other adaptation monitoring and evaluation mechanisms (EUK, RUK, and SEUK, 2025).

For security of supply, the process is well established with NESO in GB and SONI in NI performing regular assessments to inform resource adequacy (NESO, 2025a; EirGrid and SONI, 2025). These processes provide a mechanism to continue to assess the implication of changes in climate to the energy sector on a regular basis.

Assessment on the evidence base and evidence gaps

The range of electricity generation technologies included in sector level ARPs is increasing, with ARP3 expanding coverage to include 50 MWe to 100 MWe distributed thermal plants (Energy UK, 2021) and >100 MWe wind turbines and ARP4 expanding in the trade bodies represented (EUK, RUK, and SEUK, 2025). However, the ARP4 report lacks sufficient detail to enable understanding of the climate resilience of individual companies (Ofgem, 2025a) and greater insight into plant level. With a larger share of the generation mix covered by distributed generation, understanding the impacts on smaller scale distributed generation is also currently a gap (Gordon et al., 2021). Efforts to understand the changing effects to security of supply are growing, but there are remaining gaps in understanding the impacts of climate related high-impact low-likelihood events and uncertainty management (Bloomfield, 2025; Dent et al., 2024). Licence conditions set out requirements for NESO to take on new responsibilities related to resilience and security including understanding of the impacts from extreme weather hazards now and in the future (Ofgem, 2025a). Given the anticipated growth in energy storage, more evidence is needed around the management of systems with a high penetration of storage. Concerted efforts to bridge energy and climate modelling in the UK and around the world are producing substantive collaborations and research, particularly covering the impact of climate on electricity generation (Craig et al., 2022; Energy Systems Integration Group, 2023).

6.2.2.2 England

Most of the climate risk for this sector is GB-wide, and therefore the devolved nations will experience similar current and future drivers of risk; current and future magnitude of risk; and levels of preparedness of risk. In 2023, electricity generation in England came from renewables (42%), nuclear (15%), gas (38%) and other fuels (5%), with wind alone accounting for 22.7% (DESNZ, 2024a). By 2030, the UK's remaining nuclear plants are anticipated to be Sizewell B, one unit at Hinkley Point C, and a lifetime extension of one Advanced Gas-cooled Reactor unit (NESO, 2024a). Nuclear assets are highly resilient to the near-term potential effects of climate change, and the Office for Nuclear Regulation continues to follow up on the industry's commitments to update safety and security cases, ensuring resilience into the future (ONR, 2024). With the majority of existing thermal power plants located in England, water availability is an important consideration as temperatures increase (Byers et al., 2020). Under a 2 °C warming scenario, Sayers et al. (2020) identified 229 power stations in the 2020s exposed to significant risk from flooding. A 2030s scenario was not provided but is anticipated to show greater risk as the 2050s and 2080s show higher exposure, reaching 410 stations in 2080 for a 4 °C scenario (Sayers et al., 2020). The CCC (2025a) evaluated progress on adaptation of the energy sector in England and found limited progress on delivery and implementation, partial policies and plans for reducing vulnerability of energy assets to extreme weather, and limited policies and plans for system level security of supply.

Evaluation of Urgency Score

The urgency assessment for England is More Action Needed due to the Medium magnitude and confidence out to the 2030s. The risk magnitude is anticipated to increase to High in the 2050s and 2080s due to the substantial increase in exposure, with Low confidence due to the rapidly changing generation supply mix and lack of quantitative assessments of impact. However regular assessments of the security of supply by NESO suggest that adaptation will contain risk at present levels.

Table 6.9: Urgency scores for I2 Risks to electricity generation for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England								
I2 Risks to electricity generation.								
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (M)	++ (M)	++ (M)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	++ (M)	++ (M)	++ (M)	+ (M)	+ (M)	+ (M)	+ (M)	+ (M)
Urgency scores	MAN	MAN		FI			FI	
Overall urgency score	MAN							

6.2.2.3 Northern Ireland

Most of the climate risk for this sector is similar to that of GB, and therefore NI will experience similar current and future drivers of risk, and current and future magnitude of risk. However, unlike other devolved nations, NI has a separate regulator (Utility Regulator), a separate transmission system operator (SONI) and is part of a different energy market leading to different risk preparedness. In 2023, electricity generation in NI came from renewables (51%), gas (43%), coal (5%) and other fuels (1%) (DESNZ, 2024a). From 2019 to 2023 generation capacity declined from 4.0 GW to 3.3 GW in Northern Ireland, with the biggest reduction a 559 MW decrease in coal fired generation (DESNZ 2024a; Table 5.12). The ARP4 report did not include generation in NI. For energy assets in Northern Ireland, "no monitoring data on asset vulnerability" was available (CCC, 2023b). No large installations for hydropower, or power stations at risk from flooding were identified for NI (CCC, 2023b). When considering the security of supply for NI, SONI 2024/25 Winter Outlook indicated a Loss of Load Expectation of 0.23 hours but also noted 'multiple prolonged forced generator outages' from July to September 2024 and three System Alerts due to insufficient dispatchable generation (SONI, 2024). From an asset perspective, Storm Darragh recently caused significant damage at a power station in NI and forced three out of six generators into extended outages (SONI, 2025).

Evaluation of Urgency Score

The urgency assessment for NI is More Action Needed due to the Medium magnitude and confidence in the current day. While there remains limited evidence specific to Northern Ireland, Energy UK indicated most principles in their ARP4 report could be applied equally to sites in NI. Therefore, the magnitude is kept the same as the other devolved nations, but the confidence in the near future (2030s) has been lowered as a result.

Table 6.10: Urgency scores for I2 Risks to electricity generation for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland								
I2	Risks to electricity generation.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (M)	++ (M)	++ (M)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	++ (M)	+ (M)	+ (M)	+ (M)	+ (M)	+ (M)	+ (M)	+ (M)
Urgency scores	MAN	FI		FI			FI	
Overall urgency score	MAN							

6.2.2.4 Scotland

Most of the climate risk for this sector is GB-wide due to the shared market, and therefore the devolved nations will experience similar current and future drivers of risk; current and future magnitude of risk; and levels of preparedness of risk. In 2023, electricity generation in Scotland came from renewables (70%), nuclear (19%), gas (7%) and other fuels (4%) (DESNZ, 2024a). Its sole remaining nuclear power station (Torness) is planned to be decommissioned in 2030 (EDF Energy, 2025). The largest share was provided by wind, which accounted for 53.4% of Scotland's generation in 2023 (DESNZ, 2024a). Under a 2 °C warming scenario, Sayers et al. (2020) identified 10 power stations in the 2020s exposed to significant risk from flooding. A 2030s scenario was not provided but anticipated to be increased as 2050s and 2080s show higher exposure reaching 17 in 2080 for a 4 °C scenario (Sayers et al., 2020). CCC (2023b) evaluated progress on adaptation of the energy sector in Scotland and indicated insufficient data on indicators across the range of hazards and key policy milestones are largely reserved. Also, CCC (2023d) indicated it is unclear the extent to which adaptation is considered in system level security of supply.

Evaluation of Urgency Score

The urgency assessment for Scotland is More Action Needed due to the Medium magnitude and confidence out to the 2030s. The risk magnitude is anticipated to increase to High in the 2050s and 2080s due to the substantial increase in exposure, with Low confidence due to the rapidly changing generation supply mix and lack of quantitative assessments of impact. However regular assessments of the security of supply by NESO suggest that adaptation will contain risk at present levels.

Table 6.11: Urgency scores for I2 Risks to electricity generation for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland								
I2 Risks to electricity generation.								
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (M)	++ (M)	++ (M)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	++ (M)	++ (M)	++ (M)	+ (M)	+ (M)	+ (M)	+ (M)	+ (M)
Urgency scores	MAN	MAN		FI			FI	
Overall urgency score	MAN							

6.2.2.5 Wales

Most of the climate risk for this sector is GB-wide, and therefore the devolved nations will experience similar current and future drivers of risk; current and future magnitude of risk; and levels of preparedness of risk. In 2023, electricity generation in Wales came from gas (59%), renewables (34%), and other fuels (7%). The largest source of renewable generation was wind accounted for 22.5% of Wales's generation in 2023 (DESNZ, 2024a). CCC (2023c) evaluated progress on adaptation of the energy sector in Wales and identified mixed progress on security of supply, highlighting the lack of a detailed risk assessment for electricity generation in the Energy UK (2021) ARP3 Report (which remains the case in the latest ARP4 report (EUK, RUK, and SEUK, 2025)) and variable quality climate resilience plans.

Evaluation of Urgency Score

The urgency assessment for Wales is More Action Needed due to the Medium magnitude and confidence out to the 2030s. The risk magnitude is anticipated to increase to High in the 2050s and 2080s due to the substantial increase in exposure, with Low confidence due to the rapidly changing generation supply mix and lack of quantitative assessments of impact. However regular assessments of the security of supply by NESO suggest that adaptation will contain risk at present levels.

Table 6.12: Urgency scores for I2 Risks to electricity generation for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales								
I2 Risks to electricity generation.								
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (M)	++ (M)	++ (M)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	++ (M)	++ (M)	++ (M)	+ (M)	+ (M)	+ (M)	+ (M)	+ (M)
Urgency scores	MAN	MAN		FI			FI	
Overall urgency score	MAN							

6.2.3 Risks to electricity transmission and distribution systems – I3

This risk covers assets involved in the transmission and distribution of electricity, including overhead lines, underground cables, and substation equipment.

Headlines

- An urgency score of "More Action Needed" has been assigned to reflect the High Magnitude and High Confidence scores in Great Britain. Northern Ireland is recorded as "More Action Needed" for current day, and "Critical Investigation" for 2030s and 2050s as there is lower confidence due to limited evidence.
- Electricity transmission and distribution network infrastructure is expanding to support decarbonisation. This increases exposure but is also an opportunity for climate resilient design.
- Adaptation is taking place but evidence available to measure progress is limited. Increased resilience to flooding is the most advanced adaptation measure.
- The main source of evidence is ARP reports. The evidence base is strong for some hazards such as wind and floods, but less established for emerging hazards such as temperature and wildfires.

Table 6.13: Urgency scores for I3 Risks to electricity transmission and distribution systems. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I3	Risks to electricity transmission and distribution systems	**UK**	+++ (H)	+ (H)	+ (H)	+ (H)	CI
		England	+++ (H)	+++ (H)	++ (H)	++ (H)	MAN
		Northern Ireland	+++ (H)	+ (H)	+ (H)	+ (H)	CI
		Scotland	+++ (H)	+++ (H)	++ (H)	++ (H)	MAN
		Wales	+++ (H)	+++ (H)	++ (H)	++ (H)	MAN

6.2.3.1 Evidence relevant to the entire United Kingdom

Current and future drivers of risk

Electricity networks are operated by NESO in GB and SONI in NI (ENA, 2025c). The electricity network comprises around 500,000 miles of wires and cables across the UK (ENA, 2025c).

The transmission network consists of a mix of physical assets to transmit electrical energy from multiple sources of generation across the UK as well as import and export electricity between Norway, mainland Europe and Ireland (National Grid, 2024a). The UK transmission infrastructure carries electricity using approximately 7,000 km of overhead power lines carried by approximately 21,000 pylons and one high voltage subsea cable linking the grid in Scotland with the grid in England. There are over 300 substations where voltage levels are stepped up or down for purposes of transmission (at either 400 kV or 275 kV) before connecting with the ‘grid supply points’ on the distribution networks.

The electricity distribution network is divided into 14 regions with multiple connection points (grid supply points) to the transmission grid. Those 14 regions are managed by 6 Distribution Network Operators (DNOs) with a range of physical assets to step voltage up or down before supplying electricity to end users. The electricity is supplied to end-users at different voltages (132 kV, 66 kV, 33 kV, 11 kV) on the primary network and at <1 kV on the secondary (low voltage) network (BEIS, 2022a). The networks consist of transformers (ground or pole mounted) and switchgears in substations, overhead power lines on towers and poles (low voltage), underground cables, link boxes (connecting cables), smart control systems, and tunnels and bridges for carrying cables/lines.

With increasing reliance on renewable energy generation, and increasing electrification of demand, distribution networks will have increased levels of distributed generation and storage technology being connected. Smart control systems will be deployed to support the operational requirements associated with these network changes (e.g., as discussed in Marot et al., 2022). Increasing societal dependence on electricity further emphasises the importance of transmission and distribution network resilience. This is noted in sections on health (H1), built environment (BE9), digital infrastructure (I8), and economy (E1). The magnitude of risk in downstream sectors would be above and beyond what is presented in this section (I3). Both transmission and distribution networks will need to expand to support this transition.

Alongside changing risks from climate, electricity transmission and distribution networks are currently undergoing a significant transformation. NESO (2024c) anticipates 1,000 km of onshore, and 4,500 km of offshore network infrastructure will need to be built by 2030, more than double the total built in the last 10 years. At the distribution level, proactive investment of £37-£50 billion is needed by 2050, at least double current annual rates (NIC, 2025). Dependence on electricity networks is also increasing as the CCC (2025b) projects annual electricity demand to more than double from 2023 to 2050. The growth in assets increases exposure to current and future weather hazards. The extent and nature of this transition is long-term and extends beyond the 5-year price control periods that are used to inform current planning and investment decisions (see for example: ENA, 2025d; NESO, 2024c; Ofgem, 2025a; Ofgem, 2025b; Ofgem, 2022c). This indicates the need for long-term building capabilities and regulatory approaches (Ofgem, 2025b).

The types of faults that assets (as described above) experience due to different weather hazards are well documented and have been summarised in Table 6.14.

Table 6.14: Summary of the range of weather hazards that impact transmission and distribution networks. Information taken from Hawker et al. (2024) and ARP4 reporting.

Hazard	Impact
Extreme Heat	Transformer insulation degradation under high operating temperature reduces asset lifespan as well as reducing performance; Overheating/insulation failure of switchgears; Derating of underground cables to avoid exceeding upper temperature thresholds that degrade both cable

	insulation and can lead to cable deformation; Derating of overhead power lines to address issues of line sag and safe ground clearance (McGuire et al., 2025; Guddanti et al., 2025).
Extreme Cold*	Ice accumulation on lines causing sag/collapse; Leakage of SF6 gas/oil in switchgears.
Excessive rainfall	Flooding leading to inundation/damage to ground-level substations, transformers, switchgears, control equipment; Accelerated aging of poles; Damage to underground cables and cable junctions with ingress of water.
Low rainfall	Soil shrinkage leading to subsidence on poles and towers; Reduced thermal conductivity necessitating derating of underground cables.
Strong winds	Physical damage to poles, overhead lines, and substations; Debris impact.
Coastal flooding	Flooding and damage to coastal substations and underground cables.
Lightning	Strikes on higher voltage network are by and large controlled but can be an issue when other system assets are weakened.
Wildfires	Wildfires can both lead to 'tripping' of transmission as well as direct asset damage/destruction.
* Cold-related hazards are expected to decrease with climate change. While this is a positive outcome, it is outweighed by increases for other hazards.	

Electricity distribution and transmission operators (along with the Energy Networks Association) have published two rounds of the Adaptation Reporting Power (ARP3 in 2021 and ARP4 in 2024) in the last 5 years. The Energy Networks Association's overall report for ARP3 identified 15 current risks to the electricity network (ENA, 2021). Of these, five were associated with high temperatures, three with summer drought, four with heavy precipitation and flooding, one with lightning, one with wildfires and one with prolonged growing seasons. Risks and risk scores across the sector are largely unchanged between ARP3 (ENA, 2021) and ARP4 (ENA, 2024a). However, reviews and updates of design standards, along with observations of current impacts, have resulted in some reductions of risk (e.g., drought, transformer impacts from urban heat islands) by Scottish and Southern Electricity Networks (SSEN) Transmission and Distribution (ENA, 2024a).

Substation flooding is identified as the current risk with highest impact overall. The impact of flooding to electrical substations is further outlined in Engineering Technical Report (ETR) 138 which provides an industry standard for substation protection (ENA, 2018). The risks of fluvial, pluvial, and coastal flooding either remain flat or increase from current day to 2100.

Increase in temperature is considered the next highest risk in ARP reporting and is further exacerbated by anticipated increased cooling demand (BE9). Some distribution network operators report the difference between winter (heating) and summer (cooling) demands to have already notably reduced in comparison to historical differences (e.g., as reported by SSEN (2024) in relation to risks of transformer overheating with coincident cooling demand). Therefore, an increase in heat-related risks with coincident cooling demand increases are likely to be observed as early as the 2030s and continue into the future. McGuire et al. (2025) identified underground cables (distribution), connectors, transformers (transmission and distribution), and protection devices as the most vulnerable to extreme heat and heatwaves. Central, southern and eastern parts of England are identified as regions with the greatest potential heat related risks. Evidence from other parts of the world, however, shows that design standards and system operation can mitigate risks associated with extreme temperatures that go beyond the extremes associated with current and future UK climate scenarios (Guddanti et al., 2025).

Distribution network assets are at greater risk from high winds than transmission grid assets as they are at lower height than transmission lines, leading to increased risk from trees and other falling objects (ENA, 2016). Increases in growing season length will increase the risk to distribution network assets, as will increased risk of tree limb failure due to increased risk of disease and/or other environmental stressors (Lyttek et al., 2024). Transmission lines are also designed to withstand higher winds but can still be impacted during windstorms (Wilkinson et al., 2024).

Winds and gales have been demonstrated as the dominant cause of weather induced faults in northern parts of Great Britain (Souto et al., 2024). Despite reporting of significant impact from winds during storm events such as Arwen and Eunice (BEIS, 2022b), ARP3 and ARP4 largely ignore wind and storm hazards in climate risk assessment. This was based on an understanding at the time that the climate change signal in storm strength and wind (gust) speeds contained relatively large uncertainty compared to natural variability (Wallace et al., 2020) and so could not be assessed from a climate change risk perspective. Continued observed impacts from storms and recent research (Manning et al., 2023a) shows this hazard increasing into the future (see State of the Climate Chapter for further discussion) Extensive studies have been carried out to estimate the fragility of electricity networks to wind and show that impacts grow as wind speeds increase (Wilkinson et al., 2022). The impacts are further affected by factors such as localised network resilience and compounding effects such as season or wind direction (Donaldson et al., 2023; Manning et al., 2024; Manning et al., 2025).

Some UK electricity demand is met via international generation, relying on connection to electricity systems in Norway, Denmark, France, Belgium, the Netherlands and the Republic of Ireland, which provide 9.3 GW capacity for both import and export of electricity. Typically, and currently, the UK is a net importer of electricity: importing a total of 43.7 TWh (net 33.4 TWh) or 16% of total electricity demand in 2024 (DESNZ, 2025b). This reliance on interconnection means that there is an international dimension to system vulnerability, including simultaneous stress in interconnected countries from weather hazards (Bloomfield, 2025). This has been recognised in the European Union strategy on climate change adaptation, highlighting that “climate change impacts across borders” matter for energy markets and supplies (European Environment Agency, 2025). Although the UK is no longer in the EU, it shares multiple interconnections with the EU and EEA nations. Due to the location of the above ground interconnector assets being along the coast, the primary current risk to interconnectors comes from coastal (sea level rise and storm surge) and river flooding, with risk from high temperature and heatwaves becoming an issue by 2050 (National Grid Ventures, 2024).

Assessment of current magnitude of risk

The assessment of present-day risk is based on reported impact of weather in the ARP reports, and industry documented cost resulting from consumer compensation and the repair of network assets. Specifically, named storms have brought substantial disruption to electricity distribution networks in the UK. For instance: in 2021 storm Arwen resulted in a loss of power for over 1 million customers, with approximately 40,000 without power for more than three days (Ofgem, 2022a); in 2022, storms Dudley, Eunice, and Franklin caused loss of power to over 1 million homes (Met Office, 2022a); in 2023, Babet and Ciarán each led to loss of power to over 100,000 customers (Wright et al., 2024); and in 2024, storms Darragh and Éowyn led to power losses to ~259,000 (Energy Networks Association, 2024b), and ~621,000 (Energy Networks Association, 2025a) customers, respectively. Storm Éowyn led to significant power cuts across NI, with loss of power to ~285,000 households, requiring 12 days to fully restore power to over 99% of affected households (Northern Ireland Electricity Networks, 2025).

Each storm represents a significant disruption as well as financial expense. In the case of Arwen, DNOs paid nearly £40 million across consumer resilience funds and compensation payments (Ofgem, 2022a), and approved investment across all DNOs in response to this disruption was in the order of £150m (Ofgem, 2024), with network resilience costs for 2021-22 reported as £133m (Ofgem, 2022b).

Other extreme weather events besides storms have led to disruption in supply. For example, the heatwave in July 2022 strained distribution networks and led to power cuts across parts of England (Met Office, 2022b). Wildfires are reported as an emerging issue. Despite warming, snow and ice accumulation remain a risk (albeit reducing) to network assets (Wright et al., 2024). Reported impacts from extreme events inform current magnitude of risk, including those from storms despite there being no observed climate change signal in present-day storm intensity (gusts upward of 100 mph; Kendon et al., 2024).

Assessment of future magnitude of risk

<u>2030s, central warming scenario:</u>

Evidence shows the risk is anticipated to increase due to increasing hazard and exposure. Significant building of infrastructure is expected between present day and the 2030s (DESNZ, 2025e). The size of the network (in terms of number of assets) will increase along with reliance on the network with further electrification of heating and transport. The profile of asset vulnerability (i.e., the types and relative proportion of types of vulnerability) is not expected to change significantly, however the increase in network size will lead to increased exposure to hazards. ARP4 reports show an increase in the underlying magnitude scores in some risks from the present day. These increases in score, however, are insufficient to change magnitude band. This gives high confidence that magnitude will, remain at least high.

<u>2050s, central and high warming scenarios:</u>

Evidence shows the risk is anticipated to increase due to the increasing hazard and exposure. However, the increase is not sufficient to move into the Very High category. The frequency of high wind, high rainfall and severe storm events is expected to increase (Manning et al., 2024; 2023a) from a 1981-2000 baseline. These studies give insight into changes in wind gust speed for the high warming scenarios that overlap the 2050s and 2080s time periods. Further changes in windstorm intensity, extreme heat, precipitation, and extreme cold temperature for different UK regions for the same high warming scenario and time periods are shown in Manning et al. (2023b). Overall, high temperature extremes are expected to increase, cold temperature extremes to decrease, and there will be little change for wind and precipitation extremes.

As the system decarbonises, it is expected that by the 2050s a much greater degree of localised storage, generation, and associated control systems will be implemented. These distributed network assets will bring changes to the level of exposure and types of vulnerability to weather that are not yet fully understood, thereby providing uncertainty in assessing risk magnitude.

Based on the changes in hazard intensity and uncertainty in levels of system exposure, there is medium confidence that risk magnitude will, be at least high.

<u>2080s, central and high warming scenarios:</u>

Evidence shows the risk is anticipated to increase due to increasing intensity of hazards and increasing level of exposure. However, the increase is not sufficient to move into the very high category. The uncertainty in the way the transmission and distribution networks develop out to the 2080s lowers the confidence scores given to the risk magnitude. Existing assets will have similar vulnerability as present day but will be affected by aging, changes in network operation, as well as increased weather hazards. The resilience of future assets to weather extremes remains uncertain.

Based on the changes in hazard intensity and uncertainty in levels of system exposure, there is Medium confidence that risk magnitude will be at least high.

Level of preparedness for risk

Network companies have submitted to all four ARP rounds and network operators' climate resilience strategies are reported (Ofgem, 2025a) to have improved. Their Climate Change Adaptation Working Group (established in 2009) enables knowledge exchange and there is improved collaboration across companies on standardising measures of climate resilience and dealing with shared risks. Work is underway to develop climate resilience metrics and indicators initially for the distribution networks, followed by the wider sector (Ofgem, 2025a). However, Ofgem (2025a) indicates challenges remain, including the valuation of resilience measures, uncertainty around climate risks indicated in ARP4, and addressing cascading, compound and interdependent risks. The sector has developed adaptive pathways to support resilience planning.

Current design standards of underground assets, such as cables, used in the transmission system are reported as designed to withstand the more extreme temperature conditions projected in the UK (ENA, 2024a). Further work to review standards which support resilience to future climate is underway (Ofgem, 2025a). Future resilience will further depend on changes in demand, network asset aging, replacement and development, and network management. These dependencies contain significant uncertainty, but this is reflected in the adaptive planning approaches set out in ARP4 reporting. Changes to electricity demand, due to changes in climate, will impact on system loads and ability to compensate for reduced capacity under extremes (see BE9 and Wright et al., 2024). In the reporting period RIIO-ET2 (Ofgem, 2021) an average transmission asset life expectancy of 45 years is used to allow asset depreciation/replacement cost to be calculated for customer charges. An Ofgem commissioned report (CEPA, 2024) states that asset management can extend the current life expectancy range (of 41-70 years) for 'traditional' assets (i.e., cables, transformers, and switchgears). The assets of today will, therefore, likely be subject to the climate change hazards of the 2050s and 2080s. Impacts of climate change on aging assets poses additional uncertainty (National Grid, 2024b).

Assessment on the evidence base and evidence gaps

ARP reporting provides a good overview of the risks and adaptation actions underway. There is an increased understanding in relation to expected increases in storm and wind intensity, however more research is required to understand why some storms are responsible for larger power outages than others, and how this may change in the future (Wilkinson et al., 2024). More research is also needed on thresholds of vulnerability for individual assets, particularly when it comes to temperature, to inform wider system resilience.

There is a disparity in the level of evidence across hazards. For flooding and windstorms, there are observational records from recent extreme weather events and research on increasing severity and frequency of these events and associated their impacts. Current observations of failures and their association to extreme temperatures is limited, as is understanding of specific asset-type and wider system risks, when considering new assets related to grid decarbonisation (e.g., battery storage) and changing load profiles (McGuire et al., 2025). Greater clarity is needed on the role climate change should have on current and future design standards of assets. This should be informed by expected life of assets.

Evidence on the risks and adaptation planning for Northern Ireland was limited in comparison to other UK nations as the network operators are not subject to the same adaptation reporting power as those operating in Great Britain. Ofgem require submission of climate resilience strategies for electricity transmission and distribution companies but lack a clear metric to quantify resilience (Ofgem, 2025a). This is being developed as part of Ofgem's framework for electricity distribution price control for the period of 2028 to 2033 (RIIO-ED3), and ongoing work of the ENA's Climate Change Resilience Working Group (CCRWG). The National Energy NESO also plays a strategic role in ensuring the network is designed to maintain security of supply with future climate in mind, but given the nascency of the organisation, limited information is available as to the consideration of resilience in Strategic Spatial Energy Plans (CCC, 2025b).

6.2.3.2 England

The high voltage transmission network for England and Wales includes 4,500 miles of high voltage lines and underground cables and is owned and maintained by National Grid Electricity Transmission (National Grid Electricity Transmission, 2024). There are five major DNOs in England: SP-ENWL, NGED, NPG, SSEN and UKPN (ENA, 2025b), each of which filed ARP3 and ARP4 reports. As many of these companies cover multiple devolved nations, most of the climate risk for this sector is not differentiated between nations in these reports.

There are some noted differences in projected changes of extreme (hazardous) weather for the distribution network regions covering England (Manning et al., 2023b). Northwest England is projected to experience more intense windstorm events by 2060-2080, with minor, or no changes elsewhere in England. While an increase in high temperatures during hot spells will be widespread, the increase in frequency is greatest in the Southeast of England. The risk of flooding is anticipated to grow across all of England as wet spells will become wetter. The risk of ice accumulation will reduce as cold spells become milder across all of England.

Evaluation of urgency score

The overall urgency score for England is given as More Action Needed. In all time periods and scenarios of warming, the magnitude of climate risk is High. Confidence for present day is based on observed recent-past weather impacts and so is High; confidence remains High for the 2030s near future. For 2050s and 2080s, both projected changes in weather extremes and changes to transmission and distribution networks reduce confidence in the magnitude scoring to Medium.

Table 6.15: Urgency scores for I3 Risks to electricity transmission and distribution systems for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England								
I3	Risks to electricity transmission and distribution systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	+++ (H)	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
With adaptation	+++ (H)	+++ (H)	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.3.3 Northern Ireland

The high voltage transmission network for Northern Ireland includes 1,500 km of high voltage (275 kV and 110 kV) lines and the distribution network includes 45,000 km of lower voltage (33 kV and lower) lines (NIE Networks Ltd, 2015). Both are owned and maintained by Northern Ireland Electricity Networks, who also operate the distribution network. The transmission network, however, is operated by an independent transmission system operator, SONI. Land connections to the Republic of Ireland transmission network leads to strong coordination with EirGrid (the Republic of Ireland’s transmission system operator).

Regionally projected changes of extreme (hazardous) weather (Manning et al., 2023b) show no significant change to windstorm intensity and corresponding impact. An increase in high temperatures during hot spells and an increase in wetter weather by 2060-2080 are both deemed significant to network risks. As with all nations, cold weather will be less severe.

Evaluation of urgency score

The overall urgency score for Northern Ireland is given as Critical Investigation. In all time periods and scenarios of warming, the magnitude of climate risk is High. Confidence for present day is based on observed recent-past weather impacts and so is High. As network operators in Northern Ireland are not subject to the same reporting as those in Great Britain, there is less evidence, so confidence scores are lower than for other nations when considering future risk, and confidence is further downgraded for adaptation as lack of reporting on adaptation plans introduces further uncertainty.

Table 6.16: Urgency scores for I3 Risks to electricity transmission and distribution systems for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland								
I3	Risks to electricity transmission and distribution systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
With adaptation	+++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
Urgency scores	MAN	CI		CI			FI	
Overall urgency score	CI							

6.2.3.4 Scotland

The high voltage transmission network for Scotland includes 10,000 km of overhead lines and undersea and underground cables which are owned and maintained by SP Energy Networks Transmission (SP Energy Networks, 2025) and Scottish Hydro Electric Transmission (Scottish and Southern Electricity Networks - Transmission, 2016). There are two DNOs in Scotland: SSEN and SPEN (Energy Networks Association, 2025b), and both filed ARP3 and ARP4 reports. As both companies cover multiple devolved nations, most of the climate risk for this sector is not differentiated between nations in these reports.

Considering projected changes in extreme weather for Scotland (Manning et al., 2023b): windstorm intensity increases for extreme storms; extreme wet spells become more frequent; and maximum temperature during hot spells will increase. As for all the UK, cold spells will become warmer and less severe.

Evaluation of urgency score

The overall urgency score for Scotland is More Action Needed. In all time periods and scenarios of warming, the magnitude of climate risk is High. Confidence for present day is based on observed recent-past weather impacts and so is High; confidence remains High for the 2030s near future. For 2050s and 2080s, both projected changes in weather extremes and changes to transmission and distribution networks reduce confidence in the magnitude scoring to Medium.

Table 6.17: Urgency scores for I3 Risks to electricity transmission and distribution systems for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland								
I3	Risks to electricity transmission and distribution systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	+++ (H)	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
With adaptation	+++ (H)	+++ (H)	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.3.5 Wales

The high voltage transmission network for England and Wales includes 4,500 miles of high voltage lines and underground cables is owned and maintained by National Grid Electricity Transmission (National Grid Electricity Transmission, 2024). There are two DNOs in Wales: NGED and SPEN (Energy Networks Association, 2025b) and both filed ARP3 and ARP4 reports. As both companies cover multiple devolved nations, most of the climate risk for this sector is not differentiated between nations in these reports. A minor increase in windstorm intensity is projected for North Wales with increases in South Wales, along with warmer and much more frequent hot spells, and more intense wet spells (Manning et al., 2023b). As with all places in the UK, cold spells will become warmer and less severe.

Evaluation of urgency score

The overall urgency score for Wales is More Action Needed. In all time periods and scenarios of warming, the magnitude of climate risk is High. Confidence for present day is based on observed recent-past weather impacts and so is High; confidence remains High for the 2030s near future. For 2050s and 2080s, both projected changes in weather extremes and changes to transmission and distribution networks reduce confidence in the magnitude scoring to Medium.

Table 6.18: Urgency scores for I3 Risks to electricity transmission and distribution systems for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales								
I3	Risks to electricity transmission and distribution systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	+++ (H)	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
With adaptation	+++ (H)	+++ (H)	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.4 Risk to fuel supply systems – I4

This risk considers the UK's entire liquid and gaseous fuel supply chain, spanning offshore production, import terminals, transmission and distribution networks, storage sites and emerging low-carbon fuels such as hydrogen and biofuels.

Headlines

- An urgency score of Critical Investigation has been assigned for all nations to reflect the High magnitude and Low confidence scores in the 2050s.
- For present day, the urgency score for England, Scotland, and Wales is "More Action Needed" (High magnitude / Medium confidence). Northern Ireland is "Critical Investigation" (High magnitude / Low confidence).
- Floods and droughts pose threats to current fuel supply infrastructure, while high temperature can reduce equipment operating capacity and cause wildfires.
- Decarbonising will reduce the exposure of oil and natural gas infrastructure. New vulnerabilities to sea level rise and coastal erosion for low-carbon fuels and CCUS facilities clustered in coastal regions should be mitigated by climate resilient design of new infrastructure.
- Evidence is primarily from ARP reports. There are very few independent and quantitative studies due to limited access to fuel supply infrastructure asset data.

Table 6.19: Urgency scores for I4 Risk to fuel supply systems. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I4	Risk to fuel supply systems	UK	+ (H)	+ (H)	+ (H)	+ (H)	CI
		England	++ (H)	++ (H)	+ (H)	+ (H)	CI
		Northern Ireland	+ (H)	+ (H)	+ (H)	+ (H)	CI
		Scotland	++ (H)	++ (H)	+ (H)	+ (H)	CI
		Wales	++ (H)	++ (H)	+ (H)	+ (H)	CI

6.2.4.1 Evidence relevant to the entire United Kingdom

Current and future drivers of risk

The UK's fuel-supply system is complex, including: offshore North Sea oil and gas fields; coastal terminals; oil refineries; gas-processing plants; pilot hydrogen production hubs; steel pipelines; local gas-pipe network; road and rail tankers; and, biofuel and biomass sector import terminals, blending facilities and pellet trains supplying generators. As we decarbonise, the composition of UK fuel-supply system will evolve, with the reduction of fossil fuel infrastructure and increase of renewable fuel infrastructure. The exact composition of future fuel supply system remains uncertain; however, National Gas (2024) in their ARP4 report assumed the size and scale of the transmission network remains the same to the end of the century, as it is independent of the gas that is transported (methane today or the emerging hydrogen economy alongside carbon dioxide in the future). With no major hydrogen transportation pipelines in operation in GB, NESO (2024a) expects limited hydrogen infrastructure by 2030. In 2030, most gas generation is anticipated to remain on the system to maintain security of supply (NESO, 2024a), but unabated gas generation will increasingly need to be replaced by gas with CCUS (Carbon Capture Usage and Storage) or hydrogen-fired turbines. The CCC seventh carbon budget Balanced Pathway phases out unabated gas capacity by 2050 (CCC, 2025b).

A summary of the main climate risks to fuel supply infrastructure is provided in Table 6.20. On hot days, refineries and gas plants struggle to cool, and clay soils heave and shrink which bends or cracks buried pipelines; wildfire is a risk to exposed assets. Cold snaps can reduce equipment capacity. Coastal floods can impact refineries, LNG, oil terminals, and can halt tanker berths, while inland floods can inundate depots and scour pipelines. Strong winds can damage above ground assets, uproot trees and damage roofs. Storms also contribute to lightning strikes and storm surges. Additionally, increases in the magnitude of dry-wet cycles in the future (Huang et al., 2024) could increase the rate of strength deterioration in strain softening clay material, potentially causing damages to buried fuel supply assets (Postill et al., 2023).

Table 6.20: Climate Hazard impacts to fuel supply infrastructure. All statements are informed by ARP4 reports unless otherwise indicated.

Climate Hazard	Potential Impact on Fuel Supply Infrastructure
Extreme High Temperatures and Drought	• Impairs cooling processes at refineries, and hydrogen and CCUS facilities. • Reduces operating capacity of equipment • Causes failure of digital and communications. • Causes shrink-swell in clay soils, leading to the bending or cracking of buried pipelines. • Increases wildfire risk that threatens above ground assets.
Extreme Low Temperature	• Reduces operating capacity of equipment.
Extreme Rainfall and Flooding	• Coastal Flooding: Batters refineries, LNG and oil terminals (National Grid Ventures 2024); can prevent tankers from docking. • River and Surface Water Flooding: Impacts inland fuel depots and scours pipelines.
Storms and High Winds	• Damages to above-ground equipment, uproots trees, and blows off roofs. • Localised events like lightning strikes can cause fault of electrical and ICT equipment.

	• Can contribute to storm surges at the coast, affecting coastal industrial clusters and offshore production facilities.

Change in vulnerability is mainly driven by replacement of old assets, especially gas pipelines. The Iron Mains Risk-Reduction / Replacement Programme (IMRRP) (Health and Safety Executives, 2025) will remove cast- or ductile-iron gas mains within 30 m of a building by 2032 and re-lay it in weld-free polyethylene or modern steel to reduce the explosion risk from pipe fracture and corrosion. This will reduce the vulnerability of gas pipelines. While proposed as a safety measure, ARP reports consider this a climate resilience measure too as polyethylene is flexible and corrosion-proof, so it tolerates shrink-swell clay, landslip and flood scour better than brittle iron, reducing the likelihood of leak or rupture during extreme wet-dry cycles. Pipeline diversions have also been mentioned by GDNs in ARP reports (Cadent Gas, 2024; NGN, 2024) as a way to provide long-term resilience to pipelines vulnerable to flooding.

Under the CCC's Balanced Pathway in which overall economy-wide oil and gas demand reduces by 65% from 2025 to 2040, while hydrogen, Carbon Capture, Usage, and Storage (CCUS) and widespread electrification increase. This reduces exposure of some legacy assets such as oil refineries, and iron gas mains as there will be a reduced role of them in the energy system because of decommissioning. However, it also creates fresh hotspots, notably large, coastal hydrogen/CCUS complexes and new pressurised-gas corridors, where multiple climate hazards co-exist. Specifically:

- **Coastal concentration of new assets:** Government-backed industrial-cluster plans site hydrogen and carbon-capture hubs at the Humber, Teesside, Merseyside, north-east Scotland and south Wales to tap existing ports and pipelines. Environment Agency "environmental-capacity" studies warn that these estuarine zones carry some of the UK's highest fluvial, tidal-surge and sea-level-rise risks, plus potential cooling-water and electrolysis-water shortages (Environment Agency, 2022, 2023a, 2024).
- **New pipeline corridors:** Projects such as East Coast Hydrogen, Project Union and the Humber Hydrogen Pipeline envisage hundreds of kilometres of high-pressure hydrogen and carbon dioxide lines by the early-2030s. These lines traverse river crossings and shrink–swell clay belts, so will need to be designed to be resilient to flood- and ground-movement hazards familiar from today's gas grid.
- **Closure or conversion of refineries:** Petroineos ceased crude processing at Grangemouth in April 2025, removing 13% of UK refining capacity (S&P Global, 2025). Such retirements reduce the number of flood-exposed liquid fuel sites. For imported products, coastal terminals remain at risk of storm surge threat.

New infrastructure should be built with climate resilient design to mitigate climate risks.

Assessment of current magnitude of risk

This risk descriptor includes major fuel types – oil, natural gas, hydrogen, and biofuels – and assesses climate risks across the entire fuel supply chain, although the amount of evidence varies across sectors. Existing evidence suggests that the biggest risks are precipitation and temperature related. Most evidence comes from gas sector ARP4 reports that utilised matrix-based risk assessment approach from the Energy Network Association (ENA) (Cadent Gas, 2024; ENA, 2021; NGN, 2024; SGN, 2024; WWU, 2024). In ARP4:

- Northern Gas Networks (NGN) identified 34 risks, 7 of which were rated medium, which can be summarised into threats from flooding, erosion, ground movement, and snow and ice. National Gas reported 28 risks, with 9 classified as medium or high. In particular, "above ground assets affected by raised temperatures" and "risk to underground pipes from river erosion" was rated high. Increased temperature may reduce asset performance, and when coupled with increased demand for gas driven electrical generation for air conditioning may pose challenges to asset operation. Erosion may make pipelines unsupported therefore susceptible to physical damages.

- Wales & West Utilities (WWU) identified 109 risks, of which 53 are rated medium or high, which mainly fall into precipitation or temperature related hazards.
- Cadent Gas reported 10 medium risks out of 22 total risk categories, mainly attributed to flood and river erosion.
- National Grid Ventures (2024) assessed fluvial and coastal flood risks to Grain LNG as high.

While NGN and Cadent report more modest risk in ARP4 as compared to the third round of ARP reports (2021) citing successful adaptation, the evidence base remains largely qualitative. Combining all the medium to high risks from ARP reports justifies annual economic loss of hundreds of million pounds.

There are no dedicated climate risk assessments for crude-oil, refined-product or multi-product pipelines, nor for import terminals. Nonetheless, the physical hazard set, exposure profile and vulnerability mechanisms closely mirror those documented for the gas grid in ARP4 with the exception that road (I5) and rail transport (I6) play a more significant role in transporting liquid fuels. Product pipelines share comparable burial depths, materials and river-crossing routes with gas pipes, meaning ground-movement, scour and flood hazards are likely to affect them in similar ways. Exposure, too, is shared: oil and gas assets cluster in low-lying coastal zones such as the Humber, Teesside and Milford Haven, where sea-level rise and storm surge could cause significant impacts although there is a lack of a detailed published information about how critical assets are exposed or protected. In addition, any weather-related disruption to road and rail transport is likely to affect fuel supply too but there is little evidence to quantify the risk from such dependency. Given these parallels in hazard, exposure and vulnerability, the additional risk from dependency on road/rail transport, and uncertainties about individual asset exposures, risk is still considered High.

Similarly, there are no climate risk assessments for North Sea oil and gas facilities. In the last five years, several minor winter-storm incidents have affected offshore installations. For example, Storm Éowyn forced another shutdown of the Triton floating production, storage and offloading vessel in January 2025 (Offshore-Energy, 2025). These minor events support retaining the overall High risk rating.

Present-day hydrogen assets are still limited to pilot electrolysers and first-wave coastal schemes such as Net Zero Teeside, HyNet North-West and East Coast Hydrogen. Many are located in low-lying estuaries where tidal surge, river flooding and water-supply stress coincide (Environment Agency, 2022, 2023a, 2024). Water use is likely to limit deployment of water intensive technologies south of the Humber and there is a high risk that these technologies won't deliver the required carbon dioxide emissions reductions or hydrogen production capacity in the short term (2025-2030) due in part to environmental challenges (Environment Agency, 2022). With few sites but high per-asset vulnerability and strong interdependence on electricity and cooling water, existing evidence reinforces the high residual risk scoring.

For biofuels and biomass, supply is imported from a handful of east-coast ports, most notably Immingham. Associated British Ports' adaptation report (APA, 2021) keeps coastal-flood and storm-delay risks in the medium band, which again reinforces an overall high risk for the whole fuel supply infrastructure.

It must be noted that existing evidence focuses on risk to infrastructure assets or individual points of the whole fuel supply system. Although it is likely that such risk could cascade into system-wide failures — such as widespread loss of home heating that impacts public health, which also depends on factors such as fuel storage or alternative routes of fuel transportation — there is little evidence (e.g., major incidents in the past or detailed published analysis) to suggest that such risk is substantial enough to change the overall risk rating.

Assessment of future magnitude of risk

Extreme weather events such as heavy rainfall and hotter temperatures and heatwaves will increase with frequency and magnitude into the future (State of the Climate Chapter). Periods of drought followed by heavy rainfall are also projected to be more frequent and greater in magnitude as climatic change intensifies. The impacts of coastal flooding and storm surges are likely to be greater as sea level rises. Soil moisture changes can create ground movement and pipe damage; Reppas et al. (2025) identify this as an increasing risk by 2080 using the RCP8.5 high-emissions scenario, driven primarily by declining summer soil moisture and intensified shrink-swell cycles in expansive clay.

As we decarbonise, the UK's energy supply landscape will evolve. Reliance on oil and gas is expected to significantly reduce, with growth in new low-carbon fuels and supporting infrastructure. Some existing infrastructure is likely to be decommissioned (such as gas distribution networks where heating is electrified), with other infrastructure being retained or repurposed (such as gas transmission network). New infrastructure will also be needed, for instance for hydrogen and CCUS. Where new infrastructure is built, there is an opportunity to build resilience in from the outset).

<u>2030s, central warming scenario:</u>

The ARP reports indicate that the changes to risk are likely to be incremental. There is unlikely to be a step-change in either climate forcing or the energy generation in the near future. Thus, while there may be some changes to infrastructure, and some intensification of climate change impacts, they are likely to be in range of present-day impacts, leading to a score of High magnitude, with Medium confidence.

<u>2050s, central and high warming scenarios:</u>

ARP4 reports assess climate risk for RCP 8.5 high warming scenario for 2050s. Two GDNs and National Gas indicate climate risk will increase, while there are no comparisons for the other GDNs. In ARP4, National Gas report a greater number of high risks; flooding and sea level rise become high risks. Wales and West Utilities (2024) reported 16 high risks in comparison with 6 for current days. Northern Gas Networks also increased their scores across most of their risk categories. Oil consumption is projected to reduce by 84% from 2025 levels by 2050, while total gas consumption is projected to reduce by 77% from 2025 levels by 2050 (CCC, 2025b). Future decommissioning of oil and gas infrastructure should reduce the exposure of this fuel supply infrastructure. The introduction of new infrastructure for low-carbon fuels including hydrogen and synthetic fuels will introduce new exposure, but using climate risk assessments for developments should mitigate risks. Considering evidence, risk magnitude is likely to stay in the High magnitude banding, but confidence reduces to Low given uncertainties associated with changing energy infrastructure.

<u>2080s, central and high warming scenarios:</u>

Climate projections indicate that the main climate hazards will intensify in 2080s (Wallace et al., 2020). The development of hydrogen and biofuel infrastructure is expected to have happened by 2080, given the UK's statutory commitment to achieve net zero greenhouse gas emissions by 2050 (CCC, 2025b). How this changes the exposure and vulnerability of fuel supply infrastructure to climate risk remains uncertain. ARP4 reports from three GDNs and National Gas have assessed the climate risk for 2100, which provides a basis for assessing the risk for 2080s, and indicate an increased risk as compared to 2050s but with lower confidence. Balancing all evidence, the risk remains High and confidence is Low.

Level of preparedness for risk

ARP4 reports from GDNs provide some evidence about the effectiveness of climate adaption. Notably, Northern Gas, Cadent Gas, and Wales and West Utilities (2024) report an overall reduction of risks in APR4 as compared to

ARP3, because of adaptation. Reported adaptation measures include flood risk assessment, proactive pipeline checks, replacing pipe mains with polyethylene pipes, implementing mitigation measures such as flood defences. Some of the actions, such as pipeline replacement, are not driven by climate resilience but are effective for reducing climate risk. However, quantitative evidence for the benefits of climate adaptation is lacking and better monitoring and evaluation is needed. Ofgem provided further requirements for climate resilience strategies for gas distribution and transmission companies as part of RIIO-3 (Ofgem, 2024; Ofgem, 2025a), but data availability is still lacking (CCC, 2025a). The transition to low-carbon fuels and associated new infrastructure is an opportunity to increase climate resilience via climate resilient design.

Assessment on the evidence base and evidence gaps

Most evidence comes from ARP4 reports from GDNs and National Gas and their main conclusions are supported by a small number of independent studies. There are no ARP reports for Northern Ireland GDNs. While the drivers of climate risks are well-known, there are very few independent studies that translate climate hazards into climate risk quantitatively by integrating vulnerability and exposure. And evidence about how risks from the fuel supply sector translates into systematic risk is also lacking. A main barrier for such studies is the lack of data concerning asset locations and conditions; these may be unavailable due to their sensitive nature and can also be incomplete or missing. Initiatives to address this include the National Underground Asset Register (NUAR) which provides access to buried utility asset data and has the potential to support climate resilience use cases (UK Government, 2025). The National Infrastructure Spatial Tool (HM Treasury, 2025a) aims to bring strategies, data and tools in a single platform to consider opportunities and constraints including flood risk for infrastructure. As part of a DSIT programme, Matthews et al. (2025) provided recommendations to support data sharing. For low carbon energy infrastructure including hydrogen and CCUS facilities, resilience is acknowledged in regulatory frameworks (DESNZ, 2025a; DESNZ, 2025b), technical codes considering climate change impacts are still emerging.

6.2.4.2 England

There are major oil, gas, hydrogen and biofuel facilities in England, especially in coastal regions such as the Humber estuary. The ARP4 high risks include flooding, erosion, and high temperature. Presently, there are an estimated 1,300 gas infrastructure assets at risk of flooding; this is to increase to 1,400 in the 2040-2060 period (Environment Agency, 2025). The more prevalent clay-rich soils and smaller-diameter distribution mains located within southeast England make this region likely to face greatest risk from pipeline damages due to drought (Reppas et al., 2025).

ARP reports indicate the magnitude of current risk to be High. Confidence is Medium; although evidence is in agreement, there is not a robust and quantitative methodology to consider vulnerability and exposure, and independent risks assessment are limited in quantity and scope. For the 2030s, the climate risks are expected to be similar to present day. There will be new infrastructure, e.g., for the Humber Hydrogen Pipeline, or for CCUS which will change exposure and create new hotspots (Humber, Teesside, Merseyside) in areas of fluvial, tidal-surge and sea-level-rise risk. These near-term changes will not change the magnitude of risk from High (Medium confidence). For future time periods, there is increased uncertainty around the impact of climate hazards on the changing energy landscape. New infrastructure should be built with climate resilient design that mitigates risk, but the magnitude and frequency of climate hazards is expected to increase. All things considered, the magnitude of risk is expected to remain within the High banding for 2050s and 2080s, but with Low confidence, as the assessment is made using Expert judgment and limited information for different scenarios from ARP reports. ARP reports do include credible adaptation plans, including adaptation measures in recent years, from which they report an associated reduction in risk. This is largely qualitative, and there are no dedicated climate risk assessments for crude-oil, refined-product or multi-product pipelines, nor for import terminals. As such, the risk magnitude after considering adaptation remains High.

Table 6.21: Urgency scores for I4 Risk to fuel supply systems for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England								
I4	Risks to fuel supply systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
Urgency scores	MAN	MAN		CI			FI	
Overall urgency score	CI							

6.2.4.3 Northern Ireland

Gas Networks Ireland is the GDN for NI, and the gas distribution network is linked to the Republic of Ireland. The pipeline infrastructure was built from the 1990s onwards (DETINI, 2008), and is newer and less extensive than for other devolved nations. There are no oil refineries. In the NI Fourth Carbon Budget (CCC, 2025c), natural gas is a transitional power source that will be phased out or paired with CCUS, with a small strategic supply of unabated gas. Hydrogen provides a solution for low-carbon electricity generation and specific sectors like chemicals, but not for heating buildings. Such transitions will change the exposure of the fuel supply sector, but developments of hydrogen and CCUS facilities should include climate adaptation within their design, mitigating risk. There are no ARP reports from NI.

Climate hazards documented in ARP reports from GB will also impact infrastructure in NI, and thus Expert judgment considers the Risk magnitude to be High for present day, as per other UK nations (Sections 6.2.4.2, 6.2.4.4, 6.2.4.5). Confidence is Low given limited evidence. For near future, the magnitude of climate hazards and energy generation landscape is unlikely to change, thus risk remains High, with Low confidence. For the 2050s and 2080s, climate hazards are expected to intensify. Exposure of the network may change if CCUS infrastructure is introduced, but there is no strategy for this at present. Assuming a similar energy generation landscape in the future, and an intensification of hazards, risk may increase, but Expert judgment considers this to remain in the High magnitude banding. There is no evidence of adaptation actions for NI, so risk magnitude is not reduced.

Table 6.22: Urgency scores for I4 Risk to fuel supply systems for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI =

Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland								
I4	Risks to fuel supply systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
Urgency scores	CI	CI		CI			FI	
Overall urgency score	CI							

6.2.4.4 Scotland

There are major oil, gas, hydrogen and biofuel facilities in Scotland in coastal places like St Fergus and Grangemouth. The ARP4 high risks; flooding, erosion, high temperature are relevant for Scotland. The 7th Carbon Budget (CCC, 2025d) proposes reducing oil and gas and further developing of plans to develop CCUS and hydrogen in the Scottish Cluster. This changes exposure; new estuarine infrastructure faces fluvial, tidal-surge and sea-level-rise risks, but climate resilient design would mitigate risks. Other industry is being retired, such as Petroineos ceasing crude processing at Grangemouth in April 2025.

ARP reports indicate the magnitude of current risk to be High. Confidence is Medium; although evidence is in agreement, there is not a robust and quantitative methodology to consider vulnerability and exposure, and independent risks assessment are limited in quantity and scope. For the 2030s, the climate risks are expected to be similar to present day. There will be new infrastructure (e.g., for CCUS) and other infrastructure may retire, which will change exposure. These near-term changes will not change the magnitude of risk from High (Medium confidence). For future time periods, there is increased uncertainty around the impact of climate hazards on the changing energy landscape. New infrastructure should be built with climate resilient design that mitigates risk, but the magnitude and frequency of climate hazards is expected to increase. All things considered, the magnitude of risk is expected to remain within the High banding for 2050s and 2080s, but with Low confidence, as the assessment is made using Expert judgment given limited information on different climate scenarios. ARP reports do include credible adaptation plans, including adaptation measures in recent years, from which they report an associated reduction in risk. This is largely qualitative, and there are no dedicated climate risk assessments for crude-oil, refined-product or multi-product pipelines, nor for import terminals. As such, the risk magnitude after considering adaptation remains High.

Table 6.23: Urgency scores for I4 Risk to fuel supply systems for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI =

Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland								
I4	Risks to fuel supply systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
Urgency scores	MAN	MAN		CI			FI	
Overall urgency score	CI							

6.2.4.5 Wales

There are major oil, gas, hydrogen and biofuel facilities in Wales such as Milford Haven. The ARP4 reports (for National Gas and Wales & West Utilities) cite high risks of flooding, erosion, and high temperature are relevant for Wales. ARP4 reports indicate the magnitude of current risk to be High. Confidence is Medium; although evidence is in agreement, there is not a robust and quantitative methodology to consider vulnerability and exposure, and independent risks assessment are limited in quantity and scope. For the 2030s, the climate risks are expected to be similar to present day, and there are unlikely to be major changes to fuel supply infrastructure. Hence the magnitude of risk will remain in the High banding (Medium confidence). For future time periods, there is increased uncertainty around the impact of climate hazards on the changing energy landscape. New infrastructure (e.g., for CCUS or biofuel facilities) should be built with climate resilient design that mitigates risk, but the magnitude and frequency of climate hazards is expected to increase. All things considered, the magnitude of risk is expected to remain within the High banding for 2050s and 2080s, but with Low confidence, as the assessment is made using Expert judgment and limited information for different scenarios from ARP reports. ARP reports do include credible adaptation plans, including adaptation measures in recent years, from which they report an associated reduction in risk. This is largely qualitative, thus the risk magnitude after considering adaptation remains High.

Table 6.24: Urgency scores for I4 Risk to fuel supply systems for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales

I4	Risks to fuel supply systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
Urgency scores	MAN	MAN		CI			FI	
Overall urgency score	CI							

6.2.5 Risks to road transport systems – I5

Road transport systems refer to all road network assets, including active travel infrastructure and bus services. Strategic roads and highways are administered by National Highways in England, Transport Scotland in Scotland, and the North and Mid Wales Trunk Road Agent and South Wales Trunk Road Agent in Wales. In Northern Ireland, both strategic roads and local roads are managed by Department for Infrastructure Roads (NI). Other local roads are typically managed by local authorities.

Headlines

- An urgency score of "Critical Investigation" has been assigned to reflect the High Magnitude and Low Confidence for this risk in the 2050s. The present day score is "More Action Needed".
- Changes in risk are driven by increased frequency and magnitude of extreme weather (e.g., flooding, landslides). Adaptation of legacy infrastructure and local roads is lagging the Strategic Road Network.
- Societal demand is changing (e.g., hybrid working, increased use of public transport and active travel). There are increasing interdependencies with electricity transmission and transmission and digital communication sectors.
- Gaps exist in standards and guidance for roads and bridges, which need updating to include extreme weather and adaptation.

Table 6.25: Urgency scores for I5 Risks to road transport systems. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I5	Risks to road transport systems	**UK**	++ (H)	++ (H)	+ (H)	+ (VH)	CI
		England	++ (H)	++ (H)	+ (H)	+ (VH)	CI
		Northern Ireland	++ (H)	++ (H)	+ (H)	+ (VH)	CI
		Scotland	++ (H)	++ (H)	+ (H)	+ (VH)	CI
		Wales	++ (H)	++ (H)	+ (H)	+ (VH)	CI

6.2.5.1 Evidence relevant to the entire United Kingdom

Current and future drivers of risk

Climate hazards damage road infrastructure, disrupt travel and the distribution of goods, and reduce road safety. Flooding is particularly impactful (e.g., Environment Agency, 2024); fluvial and pluvial flooding present increasing risk to pavements, ancillary infrastructure, and road users. Flash flooding, especially from convective storms with high rainfall intensity, is a growing risk (e.g., Valencia in 2024). Bridges and other structures are at risk of damage from scour and floating debris during high river flows (Maroni et al., 2023, 2021). Many such structures remain unassessed for flood risk, particularly on secondary routes (RAC Foundation, 2023). Moreover, climate projections indicate increased variability with more heatwaves and dry periods interspersed with very heavy rainfall episodes in summer (Kendon et al., 2023). This will raise the frequency and severity of landslides and debris flows on natural slopes (Tichavský et al., 2019; Winter and Waaser, 2024a, b; Winter et al., 2024), and increase the instability of engineered slopes, particularly older earthworks and embankments (Klaver et al., 2024; Rouainia et al., 2020; Wilks, 2015). Coastal erosion will increasingly threaten key road infrastructure, particularly in Scotland (Hansom et al., 2017) and eastern England.

Temperature induced stresses, strains, and displacements are accelerating wear on bridges and other structures. Extreme heat events are expected to become more frequent, increasing road maintenance and repair costs due to surface deformation (Mulholland and Feyen, 2021), but new temperature-resistant pavement materials are being adopted on the Strategic Road Network. Wildfire is an emerging risk (e.g., Argyll and Bute, 2024) which can damage road assets, reduce visibility (de Abreu et al., 2022; Doubleday et al., 2021), destabilise slopes, and contribute to flash flooding events (Farid et al., 2024). Wind speeds are likely to exceed operational limits for highways and bridges more frequently (National Highways, 2024). Lastly, extreme weather events occurring in close succession (e.g., storms Dudley, Eunice and Franklin in Feb 2022) are more likely under future climate scenarios. Successive events compound risk for already-damaged infrastructure can fail further, with potentially larger secondary or tertiary impacts (Gössling et al., 2023).

The vulnerability of infrastructure is exacerbated by its condition and design; long-lived assets were not designed for current or future climates. The condition of local roads is generally poorer than strategic or major roads (CCC, 2025a). Flooding, water ingress, and high temperatures were associated with a record number of potholes in the UK in 2023 (Taylor, 2024). A lack of real-time information on network impacts (particularly to key routes) can hamper resilience to extreme events (Deeming and Lamb, 2024).

Rates of walking and cycling decline during periods of adverse weather (Gössling et al., 2023), and projected increases in adverse weather events will place reliance on other modes. Adverse weather conditions (Bärwolff and Gerike, 2024; Vita et al., 2020), flooding and poor road surface conditions, including potholes (e.g., Cambridge Cycling Campaign, 2023), and grit and loose debris (Lißner et al., 2023) present an increased risk to the safety of pedestrians and cyclists, particularly those with disabilities. New cycling infrastructure is an opportunity for adaptation, particularly reducing flood risk, but unbound and thin bituminous surfaces recommended in some cycling design standards are themselves vulnerable to flood damage (Mallick et al., 2018; National Highways, 2022).

The transition to electric vehicles changes the nature of vulnerabilities to road transport, reducing the reliance on refuelling infrastructure while increasing the reliance on electricity supply – overall the level of risk is not considered to be materially increased or decreased. Pavement deterioration will be compounded by increased loadings from Battery Electric Vehicles, due to battery weight and distribution. Autonomous vehicles could make this effect worse by concentrating loads within the road pavement (Mattinzioli et al., 2023; Fares et al., 2024). Uptake of autonomous vehicles would increase the level of interdependency on digital and communications infrastructure, but digital tools could improve monitoring and maintenance of the road network.

Roads underpin other transport modes (e.g., rail, ports) and services (e.g., energy, water). Disruptions can cascade through national and international supply chains and transport networks (National Highways, 2022). Disruptions to the Strategic Road Network can significantly hamper the effectiveness of Emergency Services (National Highways, 2022).

Assessment of current magnitude of risk

The risk to road transport systems is assessed as High Magnitude with Medium Confidence across all UK nations. While relevant evidence is increasing, there is still insufficient knowledge of actual impacts to road infrastructure and resulting costs, particularly for local roads, bus services, active and new (electric and autonomous vehicles) mobility assets and infrastructure, thus supporting the Medium confidence rating. Due to the variable nature of extreme weather and exposure, the risk cannot be reliably disaggregated by nation. However, localised impacts can be severe, especially in remote rural areas.

Assessment of future magnitude of risk

Extreme weather and other climate hazards (flooding, landslides) will increase in frequency and magnitude in the future and the impact of future climate on road infrastructure, without adaptation, it is likely to increase. Existing studies often focus on one time period and climate scenario, and there is very limited evidence related to local roads, active mobility and bus services, the changing mobility landscape, and associated infrastructure (e.g., charging stations).

<u>2030s, central warming scenario:</u>

High Magnitude with Medium Confidence (central estimate). Any changes to the magnitude of the climate hazards or their impact on the changing mobility landscape are likely to remain within the high magnitude band (£ hundreds of millions). Credible adaptation plans are in place for the strategic road networks in England and Scotland, but the level of adaptation across the sector as a whole is unlikely to reduce magnitude score (Expert Judgment).

<u>2050s, central and high warming scenarios:</u>

High Magnitude (central estimate) increasing to Very High Magnitude (high estimate), where economic impacts could reach £billions per annum. Confidence is Low given lack of evidence, particularly for Northern Ireland and Wales. Credible adaptation plans are in place for the strategic road networks in England and Scotland, but the level of adaptation across the sector as a whole is unlikely to reduce magnitude score (Expert Judgment).

<u>2080s, central and high warming scenarios:</u>

Very High Magnitude with Low Confidence for Low, Medium and High climate scenarios. The impact of extreme weather and emerging risks such as wildfires could reach £billions per annum without effective adaptation. Confidence is Low given lack of evidence, particularly for Northern Ireland and Wales. Credible adaptation plans are in place for the strategic road networks in England and Scotland, but the level of adaptation across the sector as a whole is unlikely to reduce magnitude score (Expert Judgment).

Level of preparedness for risk

Current standards for road and bridge construction do not adequately account for future climate extremes, although the Design Manual for Roads and Bridges (DMRB) now includes methods for vulnerability assessment and monitoring of climate risks, but this is only mandated for motorways and strategic roads. Change of design standards is a major financial and administrative undertaking with inputs from many stakeholders. Assets in poorer condition and/or not designed for current and future climate with long design lives are a key vulnerability. There is currently no single national inventory quantifying how much road infrastructure is fit for purpose under more extreme climate scenarios (ICE, 2023). Future ARPs promise to quantify metrics and targets for adaptation, but this is currently not addressed in ARP and regulator reporting.

The most immediate challenge is to adapt legacy infrastructure, whether due to in-built design vulnerabilities or maintenance backlog, which accelerates failure. Local roads require an urgent investment, especially in flood-prone areas (CIHT, 2024) but local authorities face chronic underfunding resulting in reactive and short-term responses.

Assessment on the evidence base and evidence gaps

The CCC highlights significant evidence gaps that constrain effective policy development and implementation (CCC, 2025a). Key limitations include: insufficient data on the condition of local and unadopted roads; a lack of risk assessments or adaptation planning for private roads, active transport, bus services, and new transport modes and associated infrastructure; and a lack of assessment of the condition/suitability of existing infrastructure (bridges, slopes, tunnels), particularly to emerging climate risks like wildfires. Existing information on the costs and benefits of adaptation measures versus the “do-nothing” scenario is limited and not presented in a format amenable to strategic decision making (NIC, 2023; OBR, 2024a).

6.2.5.2 England

National Highways report increasing pressure on England’s road infrastructure due to extreme weather events, which are projected to become more frequent and severe (National Highways, 2022). Key hazards include: river and surface water flooding affecting major routes, particularly where routing alternatives are limited; extreme temperatures (e.g., 2022 heatwave, particularly Southern England); and wind (e.g., closures of the Humber bridge in 2020 and 2021 following Storm Ciara and subsequent structural repairs). Under a 4 °C global warming scenario by 2100, temperatures, wind speeds and gusts will exceed operational limits more frequently (Highways England, 2016). Under a GWL of 2 °C, a doubling of the frequency of very high fire danger levels is projected in summer, rising to a fivefold increase under a GWL of 4 °C (Perry et al., 2022).

The evidence base for England is relatively robust for the strategic road network. Approximately 95% of the strategic network is reported to be in good condition, though this does not guarantee resilience under extreme weather conditions (NAP2; UK Government, 2018). National Highways has produced detailed, hazard-specific assessments (e.g., for ARP4, see National Highways, 2024), which underpin its adaptation strategy. Adaptation measures are informed by UKCP18 projections and include revised design standards (e.g., DMRB LA114), asset-specific climate risk assessments under high-emissions scenarios (4 °C GWL), and integration of climate resilience into routine operations. Reported actions span drainage upgrades, geotechnical assessments, adoption of pavement materials resistant to high temperatures, and pavement material trials. Thin Surfacing Course Systems (TSCS), which are more heat resistant, cover over 50% of the strategic road network (National Highways, 2024), and will increase through maintenance programmes. The CCC reports a lack of credible, funded adaptation plans for local roads in England (CCC, 2025a). Increased funding for local roads maintenance has been allocated to cover periods 2023 to 2030 (DfT, 2025; HM Treasury, 2025b). Infrastructure in poor condition/poorly designed, particularly in flood prone areas, remains a significant challenge. As above, the location of critical assets is currently unknown at national level (ICE, 2023).

Evaluation of urgency score

Extreme weather and other climate hazards (flooding, landslides) will increase in frequency and magnitude in the future. OBR (2024a) estimated the whole economy costs of the 2007 and 2015-16 floods were £125 million and £287 million respectively (at 2024-25 prices). Using this evidence, the current magnitude is High, and this will raise to Very High for 2050s high scenario, and 2080s given the worsening climate hazards. Confidence is Medium at present and in the 2030's, falling to low confidence in 2050's and 2080's, given the limited evidence for future scenarios, and for how other factors (e.g., adaptation success, increased electric and autonomous vehicle and active transport uptake) will shape the vulnerability landscape. Credible adaptation plans are in place for the strategic road network but the level of planned adaptation is unlikely to significantly reduce the magnitude score for the sector as a whole for any time period; this is based on Expert Judgment given lack of evidence on the difference that adaptation actions are having on reducing risk.

Table 6.26: Urgency scores for I5 Risks to road transport systems for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England								
I5	Risks to road transport systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (VH)	+ (VH)	+ (VH)	+ (VH)
With adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (VH)	+ (VH)	+ (VH)	+ (VH)
Urgency scores	MAN	MAN		CI			FI	
Overall urgency score	CI							

6.2.5.3 Northern Ireland

Flooding poses a high risk to local roads, exacerbated by their poor overall condition (CCC, 2023a). Projections indicate a significant increase in both moderate and high wildfire risk across Northern Ireland (Perry et al., 2022). Evidence for changing risk specific to Northern Ireland is limited.

As of June 2024, planned and ongoing adaptation projects were being considered for inclusion in Northern Ireland Climate Change Adaptation Programme 2024-2029 (NICCAP3) by DAERA (Climate NI, 2024). NICCAP2 reports slope risk has been assessed on trunk roads, and update of Local Development Plan policies to account for climate change and tree surveys for windthrow risk is ongoing (Climate NI, 2025). There is currently no overarching adaptation strategy for road infrastructure in Northern Ireland. While there has been input into the updated UK Design Manual for Roads and Bridges including adaptation considerations, this does not currently substitute for specific local level planning or preparedness (Robson, 2021; CCC, 2023a).

Evaluation of urgency score

In the absence of substantive information, UK climate risks are considered relevant for roads in Northern Ireland, except for risks relating to higher temperatures affecting the more southerly regions of the UK. As such, extreme weather and other climate hazards (flooding, landslides) will increase in frequency and magnitude in the future. Northern Ireland's long coastline means high exposure of the road network to coastal flooding and erosion. In general, climate risks to roads are similar to England (excepting temperature) and thus current magnitude is High, and this will raise to Very High for 2050s high scenario, and 2080s. Confidence is Medium at present and in the 2030s, falling to Low confidence in 2050s and 2080s. There is no data indicating adaptation to road infrastructure is taking place in Northern Ireland, thus risk magnitude remains the same after considering adaptation.

Table 6.27: Urgency scores for I5 Risks to road transport systems for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland								
I5	Risks to road transport systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (VH)	+ (VH)	+ (VH)	+ (VH)
With adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (VH)	+ (VH)	+ (VH)	+ (VH)
Urgency scores	MAN	MAN		CI			FI	
Overall urgency score	CI							

6.2.5.4 Scotland

Scotland faces distinct environmental risks linked to slope instability, landslides, and coastal erosion, particularly in the Highlands and along the west coast. Remote rural communities in Scotland are particularly vulnerable to road closures because of limited or non-existent alternative routes. In 2023, Storm Babet caused extensive flash flooding in eastern Scotland, highlighting increasing exposure to short duration, high intensity rainfall events. Between 30% and 50% of Scottish coastal roads are in erodible coastal zones, making them highly vulnerable to ongoing erosion and sea level rise (see I3 in the previous Climate Change Risk Assessment Technical Report, CCRA3-IA-TR). The A83 corridor experienced multiple landslides in 2022, adding to a long history of disruption on this route (Transport Scotland, 2023). Future climate projections also indicate a significant rise in both moderate and high wildfire risk across Scotland (Perry et al., 2022).

The condition of Scotland's motorways has been improving, though dual and single carriageways have seen slight declines. Landslide mitigation works are in progress at known high risk sites, for example the repeated closures of the A83 due to multiple landslips in 2023 have prompted major investment in protective infrastructure (Transport Scotland, 2024). Recent updates to policies concerning scour, flooding, and high winds, if fully implemented would improve the resilience of transport infrastructure over time. In anticipation of more frequent and extreme heat events, Transport Scotland has developed a thin course road surfacing specification suitable for surface temperatures up to 75 °C It was also noted that Transport Scotland's "Approach to Climate Change Adaptation & Resilience (ACCAR)" (Transport Scotland, 2023) does not sufficiently address cross-sector dependencies, which may limit systemwide resilience (CCC, 2023a).

The evidence base for Scotland is moderately strong, particularly for the trunk road network. Detailed assessments from Transport Scotland and third-party analysis (RAC Foundation, 2021; CCC, 2023a) provide useful insights into network vulnerabilities and ongoing adaptation actions. However, gaps remain, especially in understanding interdependencies between sectors and within local road infrastructure. While major risks such as landslides and flooding are documented and supported by long-term incident records, information on the condition and resilience of the local road network remains limited and fragmented, complicating the evaluation of systemic preparedness.

Evaluation of urgency score

Extreme weather and other climate hazards (flooding, landslides) will increase in frequency and magnitude in the future. Economic evidence places current damage in the tens of millions (New Civil Engineer, 2023; RAC, 2021; Rennie et al., 2021; Smith et al., 2021), which relates to a High magnitude banding for Scotland. Given worsening of climate hazards this will raise to Very High for 2050s high scenario, and 2080s. Confidence is Medium at present and in the 2030s, falling to low confidence in 2050s and 2080s, given the limited evidence for local roads and on cross-sectoral interdependencies. At present, the evidence on the effectiveness and level of implementation of adaptation does not support reducing the magnitude score.

Table 6.28: Urgency scores for I5 Risks to road transport systems for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland								
I5 Risks to road transport systems.								
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (VH)	+ (VH)	+ (VH)	+ (VH)
With adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (VH)	+ (VH)	+ (VH)	+ (VH)
Urgency scores	MAN	MAN		CI			FI	
Overall urgency score	CI							

6.2.5.5 Wales

Flooding and landslips are primary drivers for asset renewal and maintenance, while a growing risk of coastal erosion under climate change has been identified (GOV Wales, 2023). Recent slope failures, such as the incident in Brecon in 2020, highlight growing landslide risk on Welsh trunk roads (St John et al., 2024). Under a GWL of 2 °C, the frequency of very high fire danger levels in summer is projected to double, rising fivefold under GWL 4 °C (Perry et al., 2022). In 2024, 7.3% of the motorway network and 2.6% of the trunk road network required close monitoring of structural condition with an additional 2.3% of the motorway and 1.7% of trunk roads added over the next four years. 0.3% and 10.3% of motorways and trunk roads respectively have “investigatory level” skid resistance (GOV Wales, 2024a).

The independent Roads Review Panel recommends priority and focus for road investment to include climate adaptation of existing road infrastructure (Nugent, 2023; GOV Wales, 2023). The CCC identifies “insufficient progress” in adaptation policies and plans for the Welsh road network (CCC, 2023c). Despite strong high-level policy commitment to transport sector adaptation in their Climate Adaptation Strategy (GOV Wales, 2024b), there are currently no regulatory targets to drive action. Furthermore, adaptation progress for local roads cannot be assessed beyond 2018/19 due to a lack of updates. The evidence base is limited, with significant gaps in current data, particularly for local roads, where monitoring has not been updated in several years (CCC, 2023a). While risk projections and observed incidents (e.g., Brecon 2020 landslide) provide useful insights, the absence of regular, granular condition data limits a comprehensive understanding of current and emerging risks.

Evaluation of urgency score

Extreme weather and climate hazards (e.g., flooding, landslips, landslides) are likely to increase in frequency and magnitude in the future. Current magnitude of risk is High, and this will raise to Very High for 2050s high scenario, and 2080s. Confidence is Medium at present and in the 2030s, falling to Low confidence in 2050s and 2080s, given the limited evidence for local roads. At present, the evidence on the effectiveness of adaptation does not support reducing the magnitude score.

Table 6.29: Urgency scores for I5 Risks to road transport systems for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales								
I5	Risks to road transport systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (VH)	+ (VH)	+ (VH)	+ (VH)
With adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (VH)	+ (VH)	+ (VH)	+ (VH)

Urgency scores	MAN	MAN		CI			FI	
Overall urgency score	CI							

6.2.6 Risks to rail transport systems – I6

This risk includes: Great Britain's (GB) railway network, which is owned, maintained and developed by Network Rail (an arm's length body of DfT); passenger and freight services operated by a mix of private and publicly owned companies; the Northern Ireland railway network, which is operated by Northern Ireland Railways (a subsidiary of Translink); Core Valley lines infrastructure, owned and operated by Transport for Wales; London Underground and other rail services operated by Transport for London (TfL); and other systems, including light rail, metro systems outside London, and heritage railways.

Headlines

- The urgency score for this risk is "More Action Needed" for England, Scotland, Wales and Northern Ireland.
- In the future, multiple strands of evidence indicate an increase in the magnitude of this risk as climate change progresses.
- The hazards with the largest effect on performance are wind, flooding and subsidence. Heat impacts have become more prominent in the past decade.
- Projected increases in risk are driven by changes in rainfall patterns, temperature and sea level, and changes in likelihood of extreme weather. These can all affect physical infrastructure performance and service delivery.
- There is evidence of planned and in-progress adaptation on the UK's railways. The extent and quality of action varies geographically and by organisation. These actions should reduce future risk, but it is too soon for there to be concrete evidence of this already happening.

Table 6.30: Urgency scores for I6 Risk to rail transport systems. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I6	Risk to rail transport systems	**UK**	++ (H)	++ (H)	++ (H)	++ (VH)	MAN
		England	++ (H)	++ (H)	++ (H)	++ (VH)	MAN
		Northern Ireland	++ (M)	++ (M)	++ (M)	++ (H)	MAN
		Scotland	++ (M)	++ (M)	++ (H)	++ (H)	MAN
		Wales	++ (M)	++ (M)	++ (M)	++ (H)	MAN

6.2.6.1 Evidence relevant to the entire United Kingdom

Current and future drivers of risk

The UK railways experience many temperature-, water- and wind-dominated hazards causing damage to infrastructure and service disruptions (Table 6.31; Palin et al. 2021; Network Rail, n.d.). Many such hazards are projected to worsen in future (State of the Climate Chapter). For Network Rail, over the period 2006-24, the three hazards with the largest effect on performance were wind, flooding and subsidence. For these, GB-wide 2006-24 delay costs were £382.8 million, £316.2 million, and £144 million respectively (Network Rail, 2024a). Delay costs due to heat have been generally higher in the past 10 years than the previous decade (Network Rail, 2024a)

Table 6.31: Summary of the range of weather hazards that impact railways. Information taken from Palin et al. (2021) and Network Rail (n.d.) except where otherwise stated.

Hazard	Impact
Heat	Buckling of the rails, excessive sag of overhead power lines, overheating of lineside equipment used in signalling, thermal comfort issues for passengers and staff.
Cold*	Freezing of points, heavy snow requiring clearance from the track, and increased slip hazards for passengers and staff at stations. Ice can cause disruption of power supply to trains powered by a conductor rail (parts of southeast England, MerseyRail, and the London Underground).
Excessive rainfall	Flooding of the track and lineside, and washout of material under the track. Damage to bridge foundations by scour in fast-flowing rivers. Landslips affecting the track substructure or depositing material onto the track.
Low rainfall	Soil shrinkage, particularly in southeast England (clay soils), which can affect the integrity of the track and the alignment of poles supporting overhead power lines.
Strong winds	Damage to overhead power lines and other structures. Vegetation or other debris on the track or power lines. Damage to train vehicles from flying debris.
Coastal flooding	Flood damage to the track and nearby structures. Sea-level rise could increase this risk in future.
Lightning	Lightning can disrupt sensitive electronics used in signalling, disrupting services.
Wildfires	Wildfire is an emerging hazard for railways that will become an increasingly significant issue in future (Preece et al., 2025).

* Cold-related hazards are expected to decrease with climate change. While this is a positive outcome, it is outweighed by increases for other hazards. A further subtlety is that as cold events become rarer the “organisational memory” for managing them will diminish, possibly reducing resilience in the long term.

Much of the UK’s railways were built before modern-day design and construction standards, although they are continuously maintained and upgraded (Palin et al., 2021). Some parts of the network are newer (e.g., HS1, Borders Railway in Scotland). HS2 is considering future climate to safeguard resilience (HS2, 2021; HS2, 2024). The railway networks are interdependent with other systems, particularly other transport systems, energy, digital and communication systems (see Section 6.2.1 for I1). Currently 39% of GB’s railway route length is electrified (England: 44%, Scotland: 33%, Wales: 7%; ORR, 2024b).

Assessment of current magnitude of risk

ARP4 reports (Network Rail, 2024b; TfL, 2024b; ArrivaRail London, 2024) quantified climate-related risks, rating some present-day risks as “major” or “severe”. Network Rail’s ARP4 report states that weather-related delays cost £370 million in the last three years (approximately £123 million p.a. on average; Network Rail, 2024b). In addition, £21 million in revenue was estimated to be lost because of the Autumn 2023 storms (GBRTT, 2024). Network Rail plans to invest around £2.8 billion during 2024-2029 (an average of £560 million per year) in “activities and technology that will help the railway cope better with extreme weather and climate change” (Network Rail, 2024a).

The costs to the rail sector of major UK floods in summer 2007 and 2015/16 were £217 million and £158 million respectively (OBR, 2024b). There is a strong correlation between earthworks failure and rainfall, with failure rates increasing with anticipated more intense and higher frequencies of extreme rainfall (Mair et al., 2021). Ilalokhoin et al. (2022) correlated delay impacts with weather events, identifying snow, flooding and wind as major contributors.

Assessment of future magnitude of risk

The information here relates to the evidence base considered as a whole (nation specific information is provided in Sections 6.0 to 6.0). In some cases, evidence from similar time horizons has been deemed to apply to the prescribed ones below (e.g., 2070s evidence used for 2080s).

<u>2030s, central warming scenario:</u>

In the absence of any literature for this time horizon, expert judgement deems the risk and confidence levels to be similar to that of the present day.

<u>2050s, central and high warming scenarios:</u>

Generally, evidence sources for the 2050s note either (a) a projected worsening of climate hazard/s, or (b) a worsening of the present-day risk profiles, evaluated via a likelihood-impact assessment (Li et al., 2024; Mulholland and Feyen, 2021; Network Rail, 2021; Network Rail, 2024b). While some quantitative risk assessments for the 2050s exist, there is no information about how future risk ratings translate into potential costs. Evidence is very rarely split out into different scenarios.

<u>2080s, central and high warming scenarios:</u>

Generally, evidence sources for the 2080s note either (a) a projected worsening of climate hazard/s, or (b) a continued worsening of risk profiles, evaluated via a likelihood-impact assessment, between the 2050s and 2080s (Li et al., 2024; Mulholland and Feyen, 2021; Network Rail, 2021; Network Rail, 2024b). While some quantitative risk assessments for the 2080s exist, there is no information about how future risk ratings translate into potential costs. Evidence is very rarely split out into different scenarios.

Level of preparedness for risk

There is a strong “safety-first” culture on UK railways (Network Rail, 2019), which reduces the risk of climate hazards to people. Nonetheless, serious accidents that include a weather/climate-related element do still occur (e.g., fatal landslip derailment near Stonehaven in 2020). Following this accident, Network Rail is delivering on recommendations from two reports (Mair et al., 2021; Slingo et al., 2021) regarding its management of earthworks and drainage assets, and its use of weather data and early warning information in operational decision-making.

Adaptation is recognised as essential by the rail infrastructure sector, and Network Rail and TfL have undertaken comprehensive risk assessments leading to adaptation actions. The rail sector have standardised a set of climate change scenarios for use by the sector (RSSB, 2024a) to harmonise data and methods and allow industry to develop consistent approaches to assess physical risks. RSSB has also assessed the adaptation maturity of the sector (RSSB, 2024b) and hosts a Climate Change Adaptation Working Group to lead a collaborative approach. The sector has considered interdependencies, for example through a TfL-led project to assess interdependencies for London’s land-based transport sector (TfL, 2024a). Key dependencies are power, drainage and flood management, telecoms, structures and assets (e.g., bridges), vegetation, and banks and slopes. Although

London-focused, some of the stated interdependencies, in particular power (HS2, 2024) are relevant for the wider railway system.

Examples of Network Rail's adaptation initiatives include: assessment of the implications of major power outages (a key upstream dependency); development of location-specific risk assessments; tools and documentation to support climate risk planning; integration of climate change considerations into standards; consideration of weather and climate change in asset management plans; and trialling the application of an "adaptation pathways" approach for some routes. Nature-based solutions (such as protection forests to manage impact of high rainfall on earthworks) are recognised as potential adaptation measures for rail infrastructure (Blackwood et al., 2022), although few studies have investigated their role for rail specifically. Train operators are also beginning to consider adaptation, though to a more limited extent (ArrivaRail London, 2024; Southeastern Railway, 2024). Train operating companies have shown the greatest improvement in climate change maturity from 2023-24 (RSSB, 2024b). The Office of Rail and Road (ORR) claims to be taking a "risk-based, proportionate and prioritised approach to [their] regulatory role for climate change adaptation" (ORR, 2024a). The DfT's draft Transport Adaptation Strategy sets out a range of proposals which support adaptation in the rail sector, including a "climate change adaptation handbook" website of adaptation case studies, and a project to explore metrics for measuring transport system resilience to provide a baseline for adaptation progress in future (DfT, 2024a; DfT, 2024b)

Assessment on the evidence base and evidence gaps

Although evidence exists for Transport for London, as described elsewhere, there is no evidence for operators of other metros, light rail (tram), and heritage rail (Fisher et al., 2024). There is limited information on the magnitude (scale and frequency) of many interacting risks. There is limited evidence on the benefits of adaptation; although plans and actions exist, it is generally too soon to measure their effectiveness.

6.2.6.2 England

Observed impacts affecting England include multiple heat-related failures across southern and eastern England in July 2022 when temperatures surpassed the tolerance levels of several aspects of Network Rail's infrastructure (e.g., overhead lines). Speed restrictions were imposed on some lines out of London in 2025 with track temperatures nearing 60 °C. Wider impacts of the 2022 heatwave included wildfires, falling trees and failure of clay earthworks, due to widespread desiccation (Slingo et al., 2024). A 40-50% drop in train performance and £30 million revenue loss was recorded during one week of this heatwave (Network Rail, 2024a). There are statistical relationships between most delay variables and high temperatures for the London Underground network (Greenham et al., 2020). Railway fault numbers show less impact in the West Midlands until specific upper or lower thresholds of weather (temperature, precipitation) are passed (Jia et al., 2024). During January 2024, Storm Henk resulted in speed restrictions and line closures across multiple railway routes in southern England (BBC, 2024a). Structures were damaged, lines flooded, and routes were blocked by fallen trees (New Civil Engineer, 2024). In London, climate impacts are expected to lead to complex changes to clay earthworks' behaviour in different seasons (Huang et al., 2024). This may lead to complex impacts for the infrastructure that these earthworks support.

It is assumed that England would make up the bulk of GB-wide cost impacts quoted by Network Rail as passenger numbers are much higher than in Scotland or Wales. Storm damage to the railway at Dawlish in 2014 was estimated to have resulted in a £50m economic loss to the South West (Network Rail, 2024c), while annual weather-related delay costs in the £millions to £tens of millions is estimated for each of Network Rail's England regions (Network Rail, 2024c,d,e,f; some values estimated from graphs, and Wales disaggregated from the Wales and Western region).

Evaluation of urgency score

Costs in the £100s of millions bracket, and other qualitative evidence of large and pervasive present-day impacts, indicates a current risk magnitude for England as High. There is no literature for the 2030s, so expert judgment deems the magnitude to be similar to the present day (High) with an equivalent level of confidence (Medium), given this is the near future. For the 2050s, the magnitude is scored as High, based on assumed costs remaining in the £100s of millions (cf. current costs above). Evidence sources quote either (a) a projected worsening of climate hazard/s (Greenham et al., 2020; Jia et al., 2024; Slingo et al., 2024; Sasidharan et al., 2023), or (b) a worsening of the present-day risk profiles (evaluated via a likelihood-impact assessment) by the 2050s compared to the present day (e.g., ArrivaRail London, 2024; Mair et al, 2021; Network Rail, 2021, 2024b; TfL, 2021, 2024b, c).

For the 2080s, the risk magnitude is Very High, based on assumed costs in the £billions. Similarly to those for the 2050s, evidence sources quote either (a) a projected worsening of climate hazard/s, or (b) a continued worsening of risk profiles, evaluated via a likelihood-impact assessment, between the 2050s and the 2080s. Based on expert judgement and by comparison with earlier time horizons, it is possible that costs could extend into the £billions by this time horizon. Confidence is Medium for all time horizons, as there are several sources in agreement.

Table 6.32: Urgency scores for I6 Risk to rail transport systems for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England								
I6 Risk to rail transport systems.								
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (VH)	++ (VH)	++ (VH)
With adaptation	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (VH)	++ (VH)	++ (VH)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.6.3 Northern Ireland

The railway network in NI is small in comparison to GB, and evidence specific to Northern Ireland (NI) is sparse with little quantitative evidence on which to base current or future risk assessments. Storms Darragh (December 2024) and Éowyn (January 2025) led to the suspension of NI’s train services by Translink (BBC, 2024b, 2025a) and many lines were blocked by fallen trees and debris (BBC, 2025a). A report prepared for Translink (unavailable online, but quoted by multiple news outlets, e.g., BBC, 2024c) suggests an increase in risk due to future sea level rise. It found that by 2040, seven locations including Londonderry and Larne lines are at high risk of rising seas. A further four are also deemed to be at medium risk by 2040. It also found that by 2100, the number of high-risk locations could rise to 13. High risk locations identified by 2100 include Larne, Derry, Castlerock, the Bann estuary, Glynn, and Ballycarry. It is not known how the assessment of the risk in the report as “medium” or “high” might relate to the CCRA4 assessment framework. When assessing the risk magnitude, it is assumed that the 2040 information is equally applicable to the 2030s and 2050s and that 2100 information is representative of the 2080s. The present-day level of risk is not quoted.

Translink (2025) notes that in 2023/24 it experienced a sharp rise in extreme weather events causing delay and disruption to railway services compared to previous years, “almost four times the 3-year average”. It also notes potential infrastructure impacts from projected increases in hazards related to temperature, rainfall and sea level. While cost is not quantified, it is stated that “the level of investment required by Translink will be scalable and comparable to that of other railway companies”.

In 2023, the CCC evaluated adaptation progress (CCC, 2023c). For the outcome “asset and system level reliability of rail network”, a “delivery and implementation” score of “mixed progress” was given, and a “policies and plans” score of “insufficient”. More recently, the Northern Ireland Climate Change Adaptation Programme 2019-2024 (NICCAP2) End of Programme Review examines the extent to which the objectives in NICCAP2 have been achieved (Climate NI, 2025). All five actions directly relevant for rail were “fully achieved” during NICCAP2, although most require ongoing efforts. Identification of rail locations at risk of extreme heat is complete. Geotechnical inspection of embankments for slope failure risk continues, as does a programme of scour risk assessment for bridges and culverts. Translink (2025) describes ongoing investment in several adaptation measures and refers to a forthcoming Climate Change Adaptation Action Strategy to be launched in 2026. This reflects general progress in response to criticisms in Robson (2021) on the lack of management of some aspects of climate related risk for transport infrastructure in NI.

Evaluation of urgency score

Expert judgement has been used to assign the same magnitude score (Medium) for NI as that assigned for Scotland (Section 6.0) and Wales (Section 6.0), because:

- NI railway network is a similar age to that of GB, albeit an order of magnitude smaller than that in either Scotland or Wales (similar vulnerability, lower exposure);
- Recent numbers of passenger journeys on Scotland, Wales, and NI railways have been of the same order of magnitude (10s of millions of journeys; similar vulnerability and exposure);
- Recent observed changes to climate in NI are similar to those for Scotland and Wales.

Considering the evidence, the magnitude score for the 2030s and 2050s is deemed similar to that for the present day (Medium), and because the end-of-century risk is demonstrably higher than that for the mid-century, the 2080s magnitude is assumed to increase to High. Confidence is Medium due to two pieces of evidence, which are in agreement. There is some evidence that NI rail adaptation is either planned or taking place. However, there is currently no quantitative evidence that can demonstrate its effectiveness. Accordingly, the urgency score is “More Action Needed”.

Table 6.33: Urgency scores for I6 Risk to rail transport systems for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI =

Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland								
I6	Risk to rail transport systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (M)	++ (M)	++ (M)	++ (M)	++ (M)	++ (H)	++ (H)	++ (H)
With adaptation	++ (M)	++ (M)	++ (M)	++ (M)	++ (M)	++ (H)	++ (H)	++ (H)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.6.4 Scotland

Observed impacts in Scotland include a derailment near Stonehaven in 2020, with the loss of three lives. The derailment occurred because the train struck debris washed out from a drainage trench following exceptionally heavy rain (RAIB, 2022). This event occurred during the Covid-19 pandemic, and it was acknowledged that "with normal passenger numbers, the casualty toll would almost certainly have been significantly higher" (RAIB, 2022). During February 2022, three named storms (Dudley, Eunice, and Franklin) occurred during the same week resulting in major transport disruption (Met Office, 2022a). Railway services were stopped across Scotland (as well as other parts of the UK), and an uprooted tree caught fire due to contact with overhead lines (Network Rail, 2022). Red weather warnings for rain issued for Storm Babet (October 2023; Met Office, 2023) prompted cancellation of services on some routes and the use of precautionary speed restrictions. Another storm, Gerrit (December 2023), caused severe disruption to post-Christmas travel. In Scotland, numerous rail services were delayed due to strong winds and speed restrictions, landslips, flooding, and trees on the lines, while a tree hit a train on the Dumbarton line and the Dundee to Glasgow line (Met Office, 2024). All rail services in Scotland were halted by Storm Éowyn (January 2025), and there was extensive damage to the network (Met Office, 2025). Weather-related delays in Scotland over 18 years reached £145 million, which is approximately £8 million per year on average (Scotland's Railway, 2024a).

In terms of preparedness for risk, Transport Scotland's (2023) "Approach to Climate Change Adaptation & Resilience" (ACCAR) describes how it plans to address climate risks relevant to the rail network, and the "Climate Action Plan 2024-2029" (Scotland's Railway, 2024b) includes "Climate Ready" commitments centred on four outcomes relating to risk, resilience, and adaptation. The CCC evaluated adaptation progress in Scotland (CCC, 2023d). For the outcome "asset and system level reliability of rail network", a "delivery and implementation" score of "mixed progress" was given, and a "policies and plans" score of "credible". They noted ACCAR was a missed opportunity to consider interactions between modes and other sectors.

Evaluation of urgency score

The present-day risk is evaluated as Medium, based on quantitative evidence (costs in the £millions, and the event that caused three fatalities), and qualitative evidence (continued evidence of significant weather impacts occurring, and the increase in earthworks failure rates). Future risk for the 2030s is evaluated as Medium magnitude: based on expert judgement, the magnitude and confidence are deemed similar to the present day.

For the 2050s, the risk is evaluated as High magnitude. Evidence sources quote either (a) a projected worsening of climate hazard/s (e.g., Slingo et al., 2024; Mair et al., 2021), or (b) a worsening of the present-day risk profiles by the 2050s compared to the present day (Network Rail, 2024b). Given that the present-day observed costs are approximately £8 million annually, it is likely that a worsening of hazards could push the risk into the £10s of millions (High) magnitude bracket.

For the 2080s, similar logic to that for the 2050s applies. While hazards are projected to worsen, it is not considered likely that annual costs will rise to the extent that they reach £100s of millions, therefore the magnitude remains High. Confidence is Medium for all time periods; there is only a small number of evidence sources for Scotland but they agree on the nature of changes. The urgency score for this risk in Scotland is "More Action Needed" for all time horizons. More evidence is urgently needed to fill significant gaps and reduce the uncertainty in the current level of understanding.

Table 34: Urgency scores for I6 Risk to rail transport systems for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland								
I6 Risk to rail transport systems.								
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (M)	++ (M)	++ (M)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
With adaptation	++ (M)	++ (M)	++ (M)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.6.5 Wales

Disruption from three named storms (Dudley, Eunice, and Franklin), which occurred during the same week in February 2022, saw all services across Wales suspended for the first time in Network Rail's history (Met Office, 2022; Network Rail, 2022). Structures and overhead lines were damaged, and debris was blown onto tracks (Network Rail, 2022). Flooding caused major disruption to multiple lines across the Welsh railway network during October 2024 (BBC, 2024d), and in December 2024 Storm Darragh led to the suspension of most rail services in Wales. Weather-related delay costs for Wales amount to approximately £36 million for 2006-22, or £2.25 million per year on average (Network Rail, 2024c).

The focus of Transport for Wales' (TfW) "Climate Adaptation and Resilience Plan" for rail is largely on the Core Valley Lines (CVL) network (TfW, n.d.). Weather-related delay costs can be estimated from TfW (n.d.) as being approximately £410,000 for the 33-month period Feb 2020 to Oct 2022, or approximately £150,000 annually, on average (assuming these costs are suitably representative). The CCC evaluated adaptation progress in Wales (CCC, 2023c). For the outcome "asset and system level reliability of rail network", a "delivery and implementation" score of "mixed progress" was given, and a "policies and plans" score of "credible".

Evaluation of urgency score

In the present day, the risk is deemed to be Medium, based on: quantitative evidence (costs in the £millions); and qualitative evidence (continued evidence of significant weather impacts occurring, and the increase in earthworks failure rates). Future risk for the 2030s is evaluated as Medium magnitude; based on expert judgement, the magnitude is deemed similar to the present day.

For the 2050s, the risk is evaluated as Medium magnitude. The logic is analogous to that used for the evaluation of 2050s risk in Scotland (Section 6.0). However, given that the present-day observed costs are approximately £2.25 million on average in Wales, it is unlikely that a worsening of hazards could push the risk into the next category (High, £tens of millions). For the 2080s, the logic is once again analogous to that used for evaluating the 2080s risk in Scotland. However, it is possible that by the 2080s, a worsening of hazards could push the risk into the High (£tens of millions) magnitude bracket.

Confidence is Medium for all time periods; although there are few evidence sources for Wales, they agree on the nature of changes. The urgency score for this risk in Wales is More Action Needed for all time horizons.

Table 6.35: Urgency scores for I6 Risk to rail transport systems for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales								
I6	Risk to rail transport systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (M)	++ (M)	++ (M)	++ (M)	++ (M)	++ (H)	++ (H)	++ (H)
With adaptation	++ (M)	++ (M)	++ (M)	++ (M)	++ (M)	++ (H)	++ (H)	++ (H)
Urgency scores	MAN	MAN		MAN			MAN	

Overall urgency score	MAN

6.2.7 Risks to aviation, shipping, and other transport systems – I7

This risk covers infrastructure and operations in the aviation, ports and shipping, and inland waterways sectors. The aviation scope includes UK-based airports and airlines. Inland waterways considers UK rivers and canals.

Headlines

- An urgency score of "Critical Investigation" is used to reflect High Magnitude and Low Confidence in the present day for Northern Ireland and Wales, in the 2030s for Scotland, and in the 2050s for England.
- For aviation, flooding, increases in average and extreme temperatures, and extreme wind are the main hazards. To date, adaptation has focussed on flooding and extreme heat. For ports and shipping, risk is mainly driven by sea level rise, coastal and surface water flooding, extreme temperatures, and increased wind loading. For inland waterways, evidence is limited. Flooding and droughts are the main hazards, in particular their impact on navigability.
- Port and airport ARP4 reports describe climate risk and adaptation progress; adaptation action is typically undertaking risk assessments, with some airport operators undertaking more significant adaptation action.
- There is little evidence of the specific interdependencies and interconnected risks for aviation, ports and shipping, and inland waterways.

Table 6.36: Urgency scores for I7 Risks to aviation, shipping, and other transport systems. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I7	Risks to aviation, shipping, and other transport systems	**UK**	+ (H)	+ (H)	+ (H)	+ (H)	CI
		England	+++ (H)	++ (H)	+ (H)	+ (H)	CI
		Northern Ireland	+ (H)	+ (H)	+ (H)	+ (H)	CI
		Scotland	+++ (H)	+ (H)	+ (H)	+ (H)	CI
		Wales	+ (H)	+ (H)	+ (H)	+ (H)	CI

6.2.7.1 Evidence relevant to the entire United Kingdom

Current and future drivers of risk

There are three main hazards driving climate risks in UK aviation sector:

- Increased flood risk from surface water, or in coastal areas due to extreme rainfall, storm surges, and sea level rise (Challinor and Benton, 2021).
- Multiple ARP4 reports identify increases in average and extreme temperatures, particularly above 40 °C could cause: overheating of terminals, staff and passenger discomfort and health issues; impeded cargo storage; structural damage to runways and aprons; and damage to digital communications infrastructure. Higher temperatures may reduce the maximum take-off weight of aircrafts due to reduced air density and lift generation. This can affect short runway airports (e.g., Orkney Islands, London City Airport) because payload can be reduced (Gratton et al., 2022).
- Extreme wind can damage key assets including air bridges and remote radar equipment, and the frequency and severity of clear air turbulence is projected to increase, particularly for flight routes near the north polar jet stream (Gratton et al., 2022). This could increase the frequency and severity of delays, cancellations, and diversions for UK aviation. Future changes to wind speed and direction can impact the take-off and landing performance of aircraft (National Air Traffic Services, 2024).

Increased seasonal average temperatures may change bird migration patterns, potentially leading to increased bird strikes with aircraft (CAA, 2024a). In addition, the changing prevalence of tropical diseases may increase staff absence, impacting operations, due to changes in temperature, rainfall, humidity, and the frequency and severity of extreme weather events (Tidman et al., 2021).

There are four key hazards driving climate risk for the port and shipping sector:

- Sea level rise can damage infrastructure and impact navigation; however, the rate and magnitude of sea level rise beyond 2050 is uncertain (Toimil et al., 2020). Impacts will vary across the UK; England and Wales could experience a 30% higher sea level rise compared to Scotland under RCP2.6 and RCP4.5, and the south-east coast of England is the most exposed region to rising sea levels (Edwards, 2017).
- Coastal ports are primarily affected by coastal flooding due to sea level rise and storm surges, as well as pluvial flooding. Inland ports are affected by fluvial and pluvial flooding, and estuarine ports by coastal, fluvial, and pluvial flooding (Verschuur et al., 2023). Multiple ARP4 reports note flooding can reduce clearance under bridges, and may limit port access for vessels, limiting access for maintenance and repairs, and accelerating infrastructure degradation and damage.
- Temperatures above 40 °C can create unsafe conditions for port workers and shipping crews, and warmer water temperatures can corrode submerged structures (Port of Dover, 2024). Southern UK ports have greater exposure to increased temperature extremes than northern ports (Poo et al., 2021).
- Increased wind loading can put stress on quay, yard, and tower cranes, increasing their vulnerability to accelerated deterioration or damage (Port of London Authority, 2021). Increases in wave height and storm surges can accelerate the deterioration of port walls and buildings, damage berths, gates and vessels, and impact operations due to safety concerns (Port of Dover, 2024).

Across the UK, inland waterways transport 15% of total domestic freight. In London, the Thames transports 56% of inland waterway traffic (including waste – see I10) due to congestion in other transport modes (Wiegmans, 2018). Flooding and drought as the two main climate hazards driving climate risk for inland waterways (Christodoulou et al., 2020):

- Flooding can reduce navigability, and increased erosion can damage infrastructure such as locks, bridges, and banks (Murphy and Grainger, 2023).
- Multi-season droughts can reduce canal water levels, creating navigational issues (Canal & River Trust, 2024a).

The interconnected nature of aviation and the ports and shipping sectors increase their vulnerability to international climate hazards. A poleward shift of the jet stream could alter the routes and duration of transatlantic flights due to changes in flight times and cause increased air turbulence (CAA, 2024a). An ice-free Arctic in the 2050s could create new shipping routes, including opening the Transpolar Sea Route (Bennett et al., 2020). This may provide shorter shipping routes and allow the UK to be a key hub for Arctic shipping; however, there are operational risks including limited satellite coverage for navigation (Lynch et al., 2022).

Assessment of current magnitude of risk

Storms can increase distance flown and cause delays and cancellations. In 2019, over 1 million extra kilometres were flown throughout Europe to avoid stormy weather, causing delays estimated to cost €2.2 million (EUROCONTROL, 2021). Recent impacts to airport operations can provide indicative costs for climate-related events and demonstrate interdependencies between aviation and other infrastructure systems. The National Air Traffic Services (NATS) flight planning system failure in August 2023 affected over 700,000 passengers over a series of days. A software error meant flight plan data needed to be processed manually, reducing capacity from 800 flight plans per hour, to 60 per hour. This cost airlines £65 million, with additional costs up to £100 million incurred by passengers, airports, tour operators and insurers (CAA, 2024b). An electrical substation fire at Heathrow Airport in March 2025 resulted in more than 1,300 flights being disrupted and over 270,000 passengers affected due to the airport being shut down for one day (Comerford, 2025; Mackintosh, 2025). This disruption was estimated to cost airlines and suppliers £20 million for halted operations for a day (Taaffe-Maguire, 2025).

Assessment of future magnitude of risk

The aviation industry faces increasing climate risks in the future. Extreme weather is projected to cause increased disruption, especially in peak travel seasons (Yesudian and Dawson, 2021). For example, by 2090, under RCP8.5, a one-day closure due to severe flooding could cost medium-sized airports up to €3 million, increasing to €18 million for major hubs (EUROCONTROL, 2021). This demonstrates the scale of costs that could be incurred due to increasing climate risks associated with other emissions scenarios and time horizons.

A modelling study that used global mean temperature rise of 2 °C showed some airports (e.g., London City Airport) falling below mean sea level, and that by 2100 under the RCP8.5 climate scenario, airport flooding caused by sea level rise could increase annual route disruptions by a factor of 69 (Yesudian and Dawson, 2021).

For ports, the impact of sea level rise is difficult to assess beyond 2050 due to the melting of the Greenland and Antarctic ice sheets with consequences for low-lying ports (Met Office, 2018). Nevertheless, ARP4 reports identify that future sea level rise could make it difficult to access lighthouses and ports, submerge areas of land mass, and compromise quays and sea defences (Groveport, 2024; Northern Lighthouse Board, 2024).

ARP4 reports also identify future risks to port infrastructure under the RCP4.5 and RCP8.5 climate scenarios up to 2100 from extreme heat, including increased costs due to accelerated degradation of assets and increased heat stress inside container handling cranes and warehouses, creating unsafe conditions for port workers (Van Houtven et al., 2022).

<u>2030s, central warming scenario:</u>

This magnitude is considered same as present day (High), due to no significant differences to today for airports, ports and inland waterways, with no significant change in climate hazards or adaptation across aviation, ports and shipping, and inland waterways. There is limited quantitative evidence for time periods and warming scenarios outside of England, thus confidence is Medium for England, and Low elsewhere.

2050s, central and high warming scenarios:

Climate projections indicate that the main climate hazards and risks will be intensified in the 2050s. ARP4 reports for airports and ports show that under the RCP4.5 and RCP8.5 climate scenarios, without adaptation, there is an increased risk from higher temperatures and flooding exacerbated by sea level rise for infrastructure and operations. Increased risk will remain in the High magnitude band; confidence is Low due to limited evidence.

2080s, central and high warming scenarios:

Climate projections indicate that the main climate hazards and risks will be further intensified in the 2080s. ARP4 reports for airports and ports show that under the RCP4.5 and RCP8.5 climate scenarios, without adaptation the increased risks and opportunities as presented for the 2050s will likely be intensified in the 2080s. Similarly, ARP4 reports for inland waterways show that under the RCP8.5 climate scenario, the increased risks presented for the 2050s will likely also be intensified in the 2080s if there is not further adaptation but remaining in the High magnitude band. Confidence is Low due to limited evidence.

Level of preparedness for risk

Adaptation actions are being developed by authorities and operators. For example, the DfT's draft Adaptation Strategy directs the CAA to develop climate adaptation guidance (DfT, 2024a).

Adaptation actions referenced in ARP4 reports from airports (e.g., Edinburgh, Glasgow) include risk assessments, drainage surveys, climate standards for construction and asset replacement, and runway resurfacing to reduce flood risk. Although most ARP4 reports outline progress on previously identified adaptation measures, some also detail planned adaptation actions for the next five years (e.g., Gatwick Airport, 2024). Some airports have undertaken flood risk assessments and updated drainage systems to mitigate flooding risks (e.g., Heathrow Airport, 2024). Others have embedded climate change adaptation into key organisational processes and strategies, developed heatwave wellbeing procedures for airport staff and passengers, and undertaken research into the potential impacts of changes to wind speed on future aircraft technology (e.g., London Luton Airport, 2024). Heathrow Airport's ARP4 report includes detail on significant adaptation action that was taken to respond to surface water accumulation across the airport in June 2023, including modelling the on-airport drainage system and analysing the impact of rainfall on existing infrastructure.

There are limited adaptation policies for ports, with resilience standards left to individual port operators (CCC, 2025a), and there is no single authority or regulator to drive adoption of adaptation. The DfT's draft 2024 Adaptation Strategy includes a targeted intervention for ports in England to trial regular monitoring of weather-related disruptions, starting in 2025.

ARP4 reports in the ports and shipping sector show adaptation investment is being made mostly in modelling, monitoring, or research projects, such as feasibility studies (Port of London Authority, 2024). Larger-scale adaptation measures include marsh restoration and raising quay walls. ARP4 reports often recommend future action but do not tend to report implemented actions to-date.

Assessment on the evidence base and evidence gaps

There are several academic and non-academic sources of high-quality independent evidence, with a notable degree of agreement. The evidence base includes comprehensive peer-reviewed studies on climate change impacts, detailed assessments of sector-specific vulnerabilities, and adaptation plans and policies. ARP4 reports typically assess the likelihood and consequence of climate hazards in risk assessments. However, ARP4 reports typically do not report on the impacts of implemented adaptation actions in the aviation, ports and shipping, and inland waterways sectors. Monitoring, evaluation, learning and reporting on adaptation is required to track the effectiveness and impacts of actions at a national level in the UK (CCC, 2025a).

Infrastructure interdependencies for the aviation, ports and shipping sectors are relatively understudied as compared to road and rail infrastructure (Steen et al., 2022). The CCC (2025a) identified that most ARP4 submissions from reporting organisations across all modes of transport qualitatively identify their interdependencies with infrastructure sectors, particularly energy, water, telecoms, ICT, and other modes of transport. However, the CCC reported only limited evidence of adaptation action that has been taken to date to manage interdependent risks.

6.2.7.2 England

In July 2022, a heatwave caused a surface defect on the runway at London Luton Airport, suspending all flights for an afternoon (London Luton Airport, 2024). The Canal & River Trust (2024b) reported an increase in inland waterway maintenance in England and Wales in 2023/24 partly due to increasing pressures of climate change.

Flooding from Storm Ciara in February 2020 led to damage to the Figure of Three Locks on the Calder & Hebble Navigation inland waterway, which cost around £3 million to repair (Canal & River Trust, 2024b). The Canal and River Trust (2024a) are increasing asset resilience, including strengthening their ten most critical culverts.

Evaluation of urgency score

The High current magnitude score for England is based on multiple sources confirming the impact of extreme weather events and long-term climate hazards on airports, ports, and inland waterways. The current confidence score is High because the evidence is robust, and there is strong consensus among experts, including multiple ARP4 reports.

Magnitude remains High in future periods based on evidence in peer-reviewed literature and ARP4 reports. Confidence in the 2030s is scored Medium because evidence is more limited or uncertain, but there is still general agreement on the conclusion. ARP4 reports typically contain adaptation plans for the aviation and ports sector; however, there is limited evidence about the implementation and anticipated effectiveness of adaptation action in the future thus the magnitude of risk is not reduced for any time period or scenario. Confidence is Low in the 2050s and 2080s because adaptation plans are focused on shorter timeframes and thus evidence for the farther future is limited.

Table 6.37: Urgency scores for I7 Risks to aviation, shipping, and other transport systems for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England							
I7	Risks to aviation, shipping, and other transport systems.						
	Present	2030		2050		2080	
		Central	High	Central	High	Low	Central	High

No adaptation	+++ (H)	++ (H)	++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	+++ (H)	++ (H)	++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
Urgency scores	MAN	MAN		CI			FI	
Overall urgency score	CI							

6.2.7.3 Northern Ireland

Currently, airport and port operators in Northern Ireland are not required to report via the Adaptation Reporting Power and there is no reported information available about the level of risk and adaptation planning for airports and ports in Northern Ireland (CCC, 2023b).

There are five commercial ports in Northern Ireland, each of which is critical for handling external trade and enabling tourism. The small number of assets drives risk because there is not sufficient capacity to absorb the impacts of climate-related delays or closures at existing ports or airports. Although climate risk assessments of these ports are not available, the evidence reviewed in Section 6.2.7.1 highlights that Northern Ireland is vulnerable to UK-wide climate hazards, in particular coastal hazards including storm surges and sea level rise.

Evaluation of urgency score

The magnitude score is High for the current and future time horizons and is based on expert judgement that evidence on climate hazards from England and Scotland can be transposed to Northern Ireland due to broadly aligned climate trends for all parts of the UK (Slingo, 2021). The exposure of ports and airports to climate hazards means that the risks associated with climate change are increased because of these critical, single points of failure. No climate change reports or adaptation plans have been published by airports or ports in Northern Ireland creating Low confidence for the current day and future periods.

The CCC's evaluation of the second Northern Ireland Climate Change Adaptation Programme (NICCAP2) identified that adaptation planning was only in its early stages across sectors, and that there was very limited evidence for the delivery and implementation of climate adaptation. The CCC was 'unable to evaluate' the asset and system level reliability of airport and port operations in Northern Ireland in the face of climate change (CCC, 2023b). NICCAP3 is currently under development. As such, adaptation does not reduce the magnitude of risk, and confidence is scored as Low.

Table 6.38: Urgency scores for I7 Risks to aviation, shipping, and other transport systems for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland	
I7	Risks to aviation, shipping, and other transport systems.

	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
Urgency scores	CI	CI		CI			FI	
Overall urgency score	CI							

6.2.7.4 Scotland

In Scotland, island communities are particularly reliant on ferry services and are therefore vulnerable to these services being disrupted. In recent years, ferry services have become increasingly unreliable and cancellations were mainly due to weather (CCC, 2023d). The small number of assets drives risk because there is not sufficient capacity to absorb the impacts of climate-related delays or closures at existing ports.

There are commitments to replace and upgrade port facilities, including a priority to adapt ferry services to be resilient to the impacts of climate change (Transport Scotland, 2023, 2024; Scottish Government, 2024). However, there is limited evidence available on the progress and implementation of adaptation commitments for airports (CCC, 2023d). Adaptation of inland waterways at the government-level may occur via environmental restoration of waterways that improves navigability, biodiversity and supports communities (SEPA, 2021; Scottish Canals, 2023).

Evaluation of urgency score

The risk magnitude is considered High for current and future time horizons based on current impacts, evidence from ARP4 reports, and adaptation actions. Confidence is High for the present day given the evidence in ARP4 reports. In the future, confidence is scored Low as the evidence is limited or conflicting, leading to weaker consensus. The CCC was 'unable to evaluate' the asset and system level reliability of airport operations in Scotland (CCC, 2023d); thus, risk magnitude is not reduced after considering adaptation.

Table 6.39: Urgency scores for I7 Risks to aviation, shipping, and other transport systems for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland				
I7	Risks to aviation, shipping, and other transport systems.			
	Present	2030	2050	2080

		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	+++ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
Urgency scores	MAN	CI		CI			FI	
Overall urgency score	CI							

6.2.7.5 Wales

The Welsh Government's Climate Adaptation Strategy (2024) includes climate adaptation outcomes for increasing the resilience of airports and ports to extreme weather events (Welsh Government, 2024a). However, the CCC's latest evaluation of adaptation policy in Wales identified that there is limited information on the implementation and effectiveness of adaptation actions for the aviation, shipping, and inland waterways sectors (CCC, 2023c).

Although Cardiff Airport reported under ARP3, the report is not publicly available and a report was not submitted under ARP4. This highlights the criticality of understanding climate change risks to the region, particularly for the only major airport in Wales. The small number of assets drives risk because there is not sufficient capacity to absorb the impacts of climate-related delays or closures at other airports.

Evaluation of urgency score

The magnitude score is High for the future time horizons and is based on the expert judgement that evidence from England and Scotland can be transposed to Wales because hazards, exposure and vulnerability are consistent, in part due to broadly aligned climate trends for all parts of the UK (Slingo, 2021). Confidence is Low due to limited data on the climate impacts to operations at Cardiff Airport, which informed the CCC's assessment of being 'unable to evaluate' adaptation progress for the asset and system level reliability of airport operations (CCC, 2023c). Thus, magnitude of risk was not reduced after considering adaptation.

Table 6.40: Urgency scores for I7 Risks to aviation, shipping, and other transport systems for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales								
I7	Risks to aviation, shipping, and other transport systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High

No adaptation	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
Urgency scores	CI	CI		CI			FI	
Overall urgency score	CI							

6.2.8 Risks to digital and communications systems – I8

Digital and communications systems considers risks to a range of infrastructure, including data centres, telephone masts, telegraph poles, fibre optic cables, and all other assets related to phone and internet connectivity.

Headlines

- An urgency score of "Further Investigation" has been assigned to reflect the Medium Magnitude and Low Confidence.
- Current and future climate risk appears moderate. Data centres are more vulnerable to high temperatures and water shortages and, if located close together, can be simultaneously impacted by a weather event. Free-standing infrastructure (e.g., telephone masts and telegraph poles) are more vulnerable to storms and high winds. Severe disruption is generally localised but is often linked to power outages due to high dependency on this infrastructure.
- Societal and infrastructure dependence on this sector is increasing. Rapid development and asset renewal is an opportunity to embed resilience.
- There are substantial evidence gaps and the available evidence can be conflicting. Risk and impact assessments are often qualitative and high level.

Table 6.41: Urgency scores for I8 Risks to digital and communications systems. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I8	Risks to digital and communications systems	**UK**	+ (M)	+ (M)	+ (M)	+ (H)	FI
		England	+ (M)	+ (M)	+ (M)	+ (H)	FI
		Northern Ireland	+ (M)	+ (M)	+ (M)	+ (H)	FI
		Scotland	+ (M)	+ (M)	+ (M)	+ (H)	FI
		Wales	+ (M)	+ (M)	+ (M)	+ (H)	FI

6.2.8.1 Evidence relevant to the entire United Kingdom

Current and future drivers of risk

There are two main types of digital infrastructure: data centres; and telecommunications networks, including telephone masts, telegraph poles, fibre optic cables, and all other assets related to phone and internet connectivity. Data centres face climate hazards such as flooding, drought, and overheating. Data centre owners and operators identified water stress and high temperatures/heatwaves the hazards of most concern, due to the consequences for cooling systems in terms of operational failure or increased energy costs (techUK, 2024). For example, the July 2022 heatwave led to internal data centre outages across the Guy's and St. Thomas's NHS Trust, taking out most of its clinical information technology systems, and taking several weeks before complete restoration (NHS, 2023). Moreover, the UK data centre sector is heavily clustered, with around 80% of UK data centres located around the M25 motorway, and a second cluster in Manchester. Where data centres are clustered, there is the potential for a single extreme weather event to impact multiple data centres simultaneously.

For telecommunications networks, Ofcom (2024a) report that some firms identify flooding as a principal risk, as well as high winds and lightning, particularly for fixed and mobile infrastructure, including cell towers. For example, storms Isha and Jocelyn (Jan 2024) caused system-level disruption of broadband provision to 5,200 Fibrus customers (BBC, 2024e). Storm Arwen in November 2021 and Storm Éowyn in January 2025 affected phone and broadband connections across the country. Storm Arwen brought a wind direction (north to north-easterly) that infrastructure is not typically exposed to (Scottish Government, 2022), and Storm Éowyn led to physical damage to telegraph poles from both the storm itself and from the impacts of falling trees (Openreach, 2025). Storm Darragh in December 2024 led to telegraph poles and overhead cable damage, with some customers in Wales without phone and broadband connection for over two weeks (BBC, 2024f).

The technological development of telecommunications infrastructure, and the replacement, renewal of existing infrastructure can both drive and reduce climate risks. Generally, the rapid pace of technological advancements and innovation in parts of the sector (ISPA UK and INCA, 2024; techUK, 2024) means some assets are short-lived, inexpensive, and are quickly replaced or updated, reducing vulnerabilities. The deployment of Fibre to the Premises (FTTP) is enhancing infrastructure resilience, as fibre-optic cables are more resistant to temperature changes (DSIT, 2024a). As of July 2024, full-fibre coverage has reached 69% of UK households – up from 57% in September 2023 (Ofcom, 2024b). The Public Switched Telephone Network (PSTN) is currently undergoing closure and replacement by Voice over Internet Protocol (VoIP). The closure of PSTN and replacement with VoIP places greater focus on the reliability of mobile networks and fixed broadband for PSTN uses an alternative power supply thereby enabling communication during local power outages that may affect mobile and broadband networks. Following Storms Arwen and Eunice in winter 2021/22 where extended power outages impacted telecommunication provision, the switch-off of the PSTN has been delayed until January 2027 out of concerns for vulnerable customers (CCC, 2025a).

Growing societal and infrastructure reliance on digital systems enhances connectivity, access, and efficiency in daily life (Gajjar, 2024) and helps build climate resilience via improved and increase monitoring systems (e.g., rail temperatures) and early warning system capabilities (e.g., for flooding). However, increased use and dependence on digital and communications systems means the extent or severity of its failure can be greater and impact essential services, e.g., Guy's and St. Thomas's NHS Trust (NHS, 2023). Increased digital dependence also exacerbates the digital divide. Those who cannot afford digital technologies, and older people, who typically use the digital technologies less could become more vulnerable, for example because they cannot access digital warning systems. Indeed, approximately a quarter of UK households (26%) had difficulty affording communications services in May 2025 (Ofcom, 2025). Digital and communications systems are also highly dependent on power systems (see I2 and I3).

Assessment of current magnitude of risk

The current magnitude of risk for digital and communications systems is Medium. Across the UK, there have been a range of reported incidents demonstrating how extreme weather events such as heatwaves and storms have led to network outages, which can cause localised severe disruption.

Assessment of future magnitude of risk

Future risk for digital and communications systems are generally scored as Medium, with the possibility of becoming High in the longer-term due to the pace of digitalisation and growing dependency on such systems in future. There is generally a consensus among network providers and the data centre industry that climate risks will increase in the future (e.g., Ofcom, 2024a; techUK, 2024; BT Group, 2025; Vodafone Group, 2023). Some of the consequences described include increased operational costs, and lower productivity from labour hours lost through heat stress.

<u>2030s, central warming scenario:</u>

Risk in the 2030s risk will be like present day, as the sector landscape and climate impacts are likely to be similar. The risk magnitude is therefore Medium (Expert judgement).

<u>2050s, central and high warming scenarios:</u>

While extreme weather events may increase, the sector landscape may have changed (e.g., more new and more resilient infrastructure). This may result in impacts across the sector remaining similar to the present day in a central warming scenario, so the magnitude would remain as Medium. However, in the high warming scenario, weather events would be more extreme in terms of frequency, severity, and extent, and therefore would likely lead to greater impacts for the sector in terms of disruption scale or extent, justifying changing the magnitude risk to High (Expert judgement).

<u>2080s, central and high warming scenarios:</u>

Both the central and high warming scenarios would bring more extreme weather events in terms of frequency, severity, and extent. This would likely lead to greater impacts for the sector in terms of disruption scale or extent, justifying changing the magnitude risk to High (Expert judgement).

Level of preparedness for risk

Governance of digital and communications systems is reserved – decision-making is set out by UK Parliament for this infrastructure and therefore has an effect across all devolved nations.

Recent legislative reforms included some recognition of climate risk through the lens of broader resilience. For instance, upgrades are underway throughout the UK, underpinned by the need for advanced, high quality, and reliable communications infrastructure and provisions for clusters or networks of knowledge and data-driven, creative or high-technology industries, per the National Planning Policy Framework (MHCLG, 2024). Full-fibre rollout, for example, is a major upgrade for the sector and will help maintain internet connectivity as it is not affected by flooding unless power is also affected, also requiring less cabinet infrastructure (Ofcom, 2024a). As of September 2024, data centres are categorised as Critical National Infrastructure (CNI) alongside energy and water systems – the first CNI designation in over a decade (DSIT, 2024b). The intent of doing this is to enable greater government support in recovering from and anticipating critical incidents, which includes adverse weather or energy supply interruptions.

The digital and communications sector currently provides no substantive reporting on climate risk (Ofcom, 2024a) and this is largely justified by: “resilience by default” design of infrastructure that extends beyond climate risks in accordance with site selection, design and build, and operation (techUK, 2024); and existing telecommunications guidance underpinning resilient networks and services (Ofcom, 2024a). This assumption of resilience and lack of quantitative climate risk assessments may lead to the sector being insufficiently prepared for future climate impacts.

Assessment on the evidence base and evidence gaps

The confidence in risks to digital and communications systems is Low. While there is some evidence and recent reports of extreme weather already impacting this sector in various ways, there are some conflicting perspectives across industry in the UK, leading to a weaker consensus.

Additionally, the evidence base regarding future climate impacts to digital and communication systems is limited. Although there was an increase in submissions from ARP3 to ARP4, future risk assessments in these and other similar publications were typically high level and qualitative (e.g., Ofcom, 2024a; ISPA UK and INCA, 2024; techUK, 2024; BT Group, 2025). There is also an evidence gap regarding longer-term time horizons, as these risk assessments often only considered a timeframe up to 2050 (e.g., BT Group, 2025; Vodafone Group, 2023).

6.2.8.2 England

The climate risk for this sector is broadly UK-wide, and therefore the devolved nations will experience similar current and future drivers of risk; current and future magnitude of risk; and levels of preparedness of risk. Specific considerations in England include the clustering of data centres in southeast England, which is projected to experience the greatest increase in summer temperatures, and where water scarcity is high risk (techUK, 2024; Section 6.2.9 for Risk I9).

Evaluation of urgency score

The urgency assessment for England is Further Investigation. The limited evidence indicates that the sector landscape and present-day weather-related impacts are likely to be similar in the near term but could increase in the longer term. Rapid infrastructure development, which is considered “resilient by design” across the sector, plus UK Government support in the sector from a broader resilience perspective (e.g., cyber security), means that the sector is expected to withstand future climate hazards; it is important to note there is limited evidence to substantiate this expectation. The examples presented here demonstrate that outages can be impactful but are usually localised. However, increasing dependency on the sector is increasing vulnerability, and individual weather events could result in farther-reaching and substantial impacts and consequences in future.

Table 6.42: Urgency scores for I8 Risks to digital and communications systems for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England				
I8	Risks to digital and communications systems.			
	Present	2030	2050	2080

		Central	High	Central	High	Low	Central	High
No adaptation	+ (M)	+ (M)	+ (M)	+ (M)	+ (H)	+ (M)	+ (H)	+ (H)
With adaptation	+ (M)	+ (M)	+ (M)	+ (M)	+ (H)	+ (M)	+ (H)	+ (H)
Urgency scores	FI	FI		FI			FI	
Overall urgency score	FI							

6.2.8.3 Northern Ireland

The climate risk for this sector is broadly UK-wide, and therefore the devolved nations will experience similar current and future drivers of risk; current and future magnitude of risk; and levels of preparedness of risk. Specific considerations in Northern Ireland include storms, particularly with high winds. Some of the windiest parts of Northern Ireland correlate with high population density, especially in and around Belfast and towards the southeast. Northern Ireland has the greatest percentage of population with access to full fibre internet at 91% as of January 2024. This is one third higher than England, which is the next highest (Uswitch, 2024). Nevertheless, Storm Éowyn, for example, still impacted phone and broadband connection across the country due to wind damage to electricity and telecoms infrastructure (BBC, 2025b).

Evaluation of urgency score

The urgency assessment for Northern Ireland is Further Investigation. The limited evidence indicates that the sector landscape and present-day weather-related impacts are likely to be similar in the near term but could increase in the longer term. Rapid infrastructure development which is considered “resilient by design” incorporated across the sector, plus UK Government support in the sector from a broader resilience perspective (e.g., cyber security) means that the sector is expected to withstand future climate hazards; it is important to note there is limited evidence to substantiate this expectation. The examples presented here demonstrate that outages can be impactful but are usually localised. However, increasing dependency on the sector is increasing vulnerability, and individual weather events could result in farther-reaching and substantial impacts and consequences in future.

Table 6.43: Urgency scores for I8 Risks to digital and communications systems for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland								
I8	Risks to digital and communications systems.							
	Present	2030		2050		2080		

		Central	High	Central	High	Low	Central	High
No adaptation	+ (M)	+ (M)	+ (M)	+ (M)	+ (H)	+ (M)	+ (H)	+ (H)
With adaptation	+ (M)	+ (M)	+ (M)	+ (M)	+ (H)	+ (M)	+ (H)	+ (H)
Urgency scores	FI	FI		FI			FI	
Overall urgency score	FI							

6.2.8.4 Scotland

The climate risk for this sector is broadly UK-wide, and therefore the devolved nations will experience similar current and future drivers of risk; current and future magnitude of risk; and levels of preparedness of risk. Specific considerations in Scotland for digital and communications systems risk would be storms, particularly with high winds, as Scotland has some of the windiest regions in the UK. For example, Storm Arwen in November 2021 and Storm Éowyn in January 2025 affected phone and broadband connections across the country.

Evaluation of urgency score

The urgency assessment for Scotland is Further Investigation. The limited evidence indicates that the sector landscape and present-day weather-related impacts are likely to be similar in the near term but could increase in the longer term. Rapid infrastructure development which is considered “resilient by design” incorporated across the sector, plus UK Government support in the sector from a broader resilience perspective (e.g., cyber security) means that the sector is expected to withstand future climate hazards; it is important to note there is limited evidence to substantiate this expectation. The examples presented here demonstrate that outages can be impactful but are usually localised. However, increasing dependency on the sector is increasing vulnerability, and individual weather events could result in farther-reaching and substantial impacts and consequences in future.

Table 6.44: Urgency scores for I8 Risks to digital and communications systems for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland								
I8	Risks to digital and communications systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+ (M)	+ (M)	+ (M)	+ (M)	+ (H)	+ (M)	+ (H)	+ (H)

With adaptation	+ (M)	+ (M)	+ (M)	+ (M)	+ (H)	+ (M)	+ (H)	+ (H)
Urgency scores	FI	FI		FI			FI	
Overall urgency score	FI							

6.2.8.5 Wales

The climate risk for this sector is broadly UK-wide, and therefore the devolved nations will experience similar current and future drivers of risk; current and future magnitude of risk; and levels of preparedness of risk. Specific considerations in Wales for digital and communications systems risk would be storms, particularly with high winds, as Wales has some windier regions in the west.

Evaluation of urgency score

The urgency assessment for Wales is Further Investigation. The limited evidence indicates that the sector landscape and present-day weather-related impacts are likely to be similar in the near term but could increase in the longer term. Rapid infrastructure development which is considered “resilient by design” incorporated across the sector, plus UK Government support in the sector from a broader resilience perspective (e.g., cyber security) means that the sector is expected to withstand future climate hazards; it is important to note there is limited evidence to substantiate this expectation. The examples presented here demonstrate that outages can be impactful but are usually localised. However, increasing dependency on the sector is increasing vulnerability, and individual weather events could result in farther-reaching and substantial impacts and consequences in future.

Table 6.45: Urgency scores for I8 Risks to digital and communications systems for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales								
I8	Risks to digital and communications systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+ (M)	+ (M)	+ (M)	+ (M)	+ (H)	+ (M)	+ (H)	+ (H)
With adaptation	+ (M)	+ (M)	+ (M)	+ (M)	+ (H)	+ (M)	+ (H)	+ (H)
Urgency scores	FI	FI		FI			FI	

Overall urgency score	FI

6.2.9 Risks to water supply and wastewater systems– I9

This chapter covers risks to municipal water supply and wastewater infrastructure and services. This includes services provided by utilities, whether privately owned (as in England and Wales) or fully government owned (as in Scotland and Northern Ireland), as well as non-utility supply, commonly known as private supplies.

Headlines

- An urgency score of "More Action needed" has been assigned to reflect the High Magnitude and Medium Confidence.
- Drought will continue to pose a major threat and flood risk will increase. There will be increasing negative impacts from combined sewer overflows. Water quality will deteriorate because of droughts and flood-related pollution.
- Wildfires and growth in high water demand industries are emerging risks.
- The climate risks to water supply and wastewater infrastructure and services increase over time. Population growth and shifts further drives risks. Private supplies may be more vulnerable.
- Adaptation plans lack specificity and monitoring of implemented actions is weak.
- More research is need on water quality changes and mechanisms (e.g., new chemical cocktails), and the impact of wildfires of catchments and service delivery.

Table 6.46: Urgency scores for I9 Risks to water supply and wastewater systems. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I9	Risks to water supply and wastewater systems	**UK**	+++ (H)	++ (H)	++ (H)	++ (VH)	MAN
		England	+++ (H)	++ (H)	++ (H)	++ (H)	MAN
		Northern Ireland	++ (H)	++ (H)	++ (H)	++ (VH)	MAN
		Scotland	+++ (H)	++ (H)	++ (H)	++ (H)	MAN
		Wales	++ (H)	++ (H)	++ (H)	++ (H)	MAN

6.2.9.1 Evidence relevant to the entire United Kingdom

Current and future drivers of risk

Climate change will increase the risk to water supply and wastewater services in the UK. Changes to rainfall patterns increase the risk from droughts and floods (see State of Climate Chapter). All these risks are important, but drought will remain the principal threat to water and wastewater services. Figure 6.4 shows the impact of a changing climate on water and wastewater services.

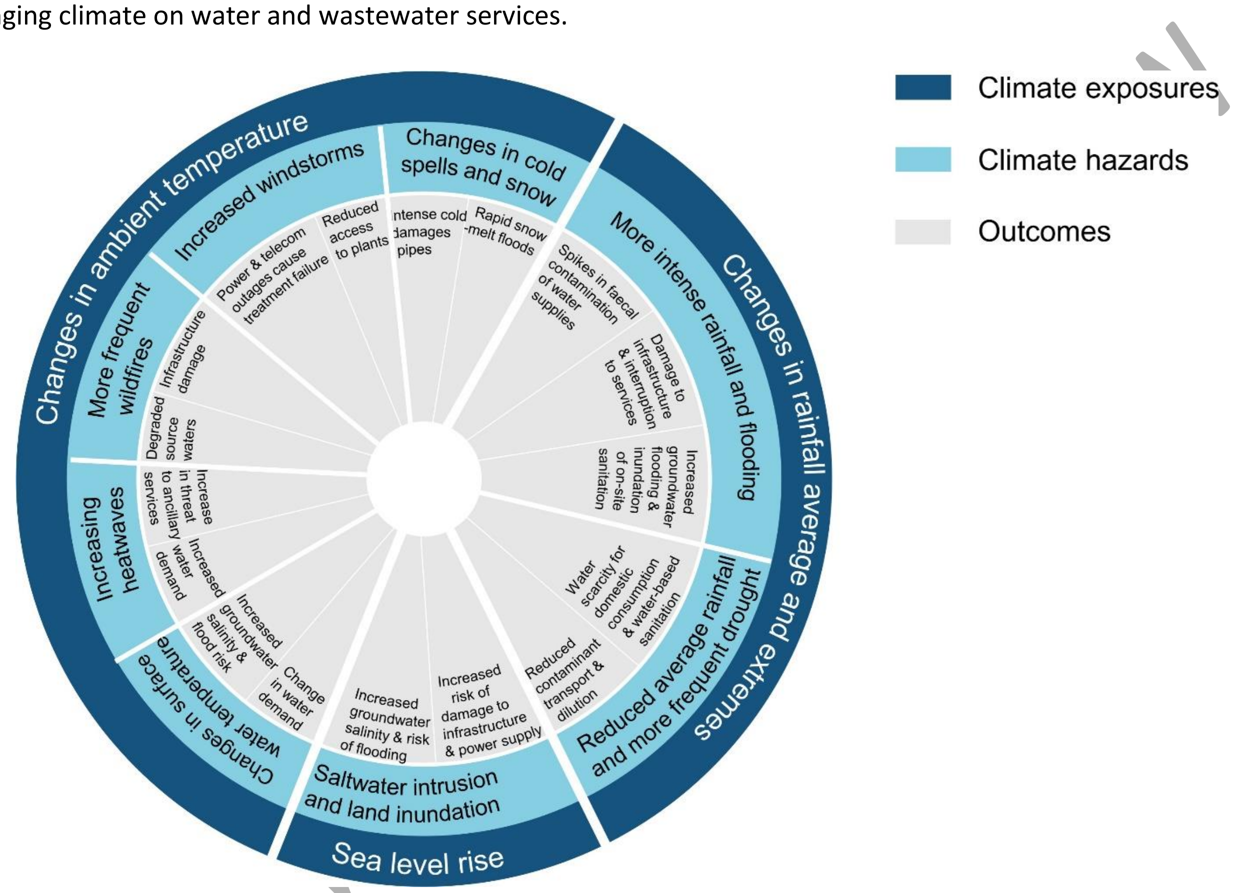

Figure 6.3: The climate wheel of impacts on water and wastewater services

Drought, floods, wildfire, and increasing temperatures degrade water quality at source, within supply systems, and in receiving waters. Storms represent a risk to ancillary services (power, telecoms, roads) that are essential for water and wastewater system functionality. Reduced water availability during hot, dry periods places a strain on public water supplies, affecting water quantity and quality. Low water availability often coincides with increased domestic demand, exacerbating strain on supply, and may lead to service interruptions.

Fluvial and pluvial flooding impact water supply and wastewater treatment sites. Wastewater facilities tend to be more vulnerable than water supplies due to their low-lying locations. Much of the UK sewer network carries both sewage and runoff from rain events in combined sewers. This increases both the risk of overflow spills from wastewater treatment works and direct flooding from overloaded sewers. Coastal flooding and erosion also present significant risks, especially to wastewater treatment sites located near coastlines (see also BE2)

Wildfires threaten catchments and critical infrastructure, and in future may change hydrology and raw water quality (Raoelison et al., 2023; Moazeni and Cerda, 2024). Windstorms create challenges for ancillary services such as power, telecoms, and roads. Storm Arwen in 2021 demonstrated that rural water supplies are vulnerable to damage to the national power grid (Valero et al., 2023). Private water supplies (e.g., 3.6% of population use in Scotland) are particularly vulnerable.

Demographic changes will increase risk. Population growth will be highest in the southeast and east of England, where drought risks are highest and increasing (State of the Climate Chapter). Population growth in the other nations is projected to be lower but regional variations are pertinent. For instance, population growth in Scotland is expected to be highest within commuting distance to Edinburgh (Scottish Government, 2021), which coincides with increasing drought hazards in east Scotland (State of the Climate Chapter). The UK population is aging, which increases vulnerability when water services are disrupted because of difficulty in accessing alternative supply and potential risks from waterborne and hygiene-related pathogens. UK water and wastewater infrastructure is aging, increasing its vulnerability to damage or disruption from climate risks.

Other risk drivers include growth in high water demand industries and energy generation. Increasing investment in data centres may increase demand for water, which in other countries has been shown to be substantial (Mytton, 2021; Watkowski et al., 2025; Liu et al., 2025). Where this investment coincides with areas of highest population growth and existing water stress (e.g., southeast and east of England), this may create new challenges in sustainable supply.

Deteriorating water quality with climate change is leading to increasing threats to human health from exposure via consumption and from recreational uses of water (UKHSA, 2023), with the very young, the old, and people with co-morbidities most vulnerable (see also H4)

Increasing water temperatures, more frequent low flow events, floods, and discharge of untreated sewage will contribute to harmful algal blooms that impact water supplies (Bussi and Whitehead, 2020; Reid et al., 2024; RAEng, 2024). Drought conditions often create higher concentrations of chemicals in water and may lead to release of contaminants in the bottom waters and sediments in reservoirs, increasing exposure to chemical ‘cocktails’ (UK Parliament, 2022). Floods degrade water quality in water bodies with sudden increases in suspended solids and chemical pollution, including from direct runoff and combined sewer overflows. The persistence of water-borne pathogens within the environment is expected to change with changes in climate presenting new challenges (Colston et al., 2022).

Assessment of current magnitude of risk

Evidence from multiple high-quality sources along with adaptation plans and strategies prepared by water companies, indicates there is currently a high risk from climate change. Risks to wastewater treatment systems, including damage to treatment facilities by flooding, including saltwater flooding, continue to exist (Hyde-Smith et al., 2022) and increasing pollutant loads can overwhelm treatment capacity in treatment plants during flood events. Water scarcity is a significant threat to municipal water supply particularly in eastern parts of the UK, with private water supplies particularly vulnerable (Visser-Quinn et al., 2021; Reyniers et al., 2023).

Current levels of pollution combined with increasing water temperatures and more frequent periods of drought and flood are increasing the risks of harmful algal blooms across the UK (Reid et al., 2024; RAEng, 2024.; Perry et al., 2024). Harmful algal blooms present a potential risk to health from the release of toxins and cause problems for water treatment (UKHSA, 2023). There is evidence that periods of low flows and drought increase risks of chemical contamination of water, including concentrations of pharmaceuticals and micro-plastics (Niemi et al. 2022; Wilson and Worrall, 2021) and discharge of untreated sewage after storm events causes chemical contamination, including from emerging contaminants (Petrie, 2021; see H2). Dissolved organic carbon is already of concern given the substantial proportion of UK catchments containing peatlands. Current maximum dissolved organic carbon concentrations in source waters already exceed treatment capacity and these will increase in the future (Xu et al., 2020). Wildfire may further contribute to raised dissolved organic carbon and may increase soil erosion and increased suspended solids and nutrients downstream. However, wildfire impacts on water supply remains under-studied in the UK.

Treatment of drinking water by water utilities is currently considered excellent across the UK. However, vulnerability to extreme weather prevails. For wastewater there is abundant evidence that water companies are not managing wastewater well and that combined sewer overflow spills occur at an unacceptable level (RAEng, 2024; Perry et al., 2024). Water quality in private supplies is of concern (Rivington et al., 2022; DWI, 2023a, b) and this is expected to worsen (Boca et al., 2022). There is little evidence that actions are being taken to manage water quality in these supplies.

Assessment of future magnitude of risk

There is consensus that drought poses the principal threat to future water supply across the UK (Boca et al., 2022; Murgatroyd et al., 2022). However, assessments of future risk indicate potential hotspots in all nations where periods of hydrological extremes may be exacerbated, such as northeast and southwest Scotland (Visser-Quinn et al., 2021) and southeast and eastern England (State of the Climate Chapter). Future flood risk is significant in all four nations. Risk of increased summer flooding will change the dynamics of water storage patterns, affect water quality and increase operation and maintenance costs. Increased flooding may trigger a cascading risk as aging infrastructure performance declines, e.g., through catastrophic dam failure (Michalis and Sentenac, 2021).

<u>2030s, central warming scenario:</u>

The risk for the 2030s is assessed as being high, based on several sources of high-quality evidence (medium confidence), with risks remaining high after considering adaptations by water companies as these do not comprehensively cover all climate threats. Drought will pose the principal threat to water supply in the future across the UK (Boca et al., 2022; Murgatroyd et al., 2022). Strategic water resource options, if implemented, can provide resilience to a 1-in-500-year drought, but without these investments, deficits will occur (Murgatroyd et al., 2022). Reuse schemes show the greatest resilience to future changes in climate and demand, followed by reservoirs and finally transfers and the greatest benefit of strategic resource options is observed in the London water resource zone (Murgatroyd et al., 2022). As part of the strategic water resource options, inter-basin transfers can be considered between non-adjacent water resources zones (i.e., from water rich to water poor zones) but in some cases may only be viable in the winter if deficits in the supplying zone are to be avoided (Dobson et al., 2020; Khadem et al., 2021). Modelled studies have focused on supply with little assessment of increased demand from population change, or water-intensive industries. Water quality will continue to decline (Xu et al., 2020; Adey et al., 2022; RAEng, 2024) as algal blooms, dissolved organic carbon, and chemical contamination continue, and combined sewer overflow events remain frequent. The deterioration in source water quality will pose risks for water treatment. Risks from wildfires and threats to ancillary services will increase and are an emerging and evolving threat which require further research.

<u>2050s, central and high warming scenarios:</u>

The level of overall risk is high. Risks of drought continue with concerns that plans to meet the regulatory requirement to be resilient to a 1-in-500-year drought event are not sufficient, unless all strategic resource options are implemented and supported by additional water demand measures (Murgatroyd et al., 2022). Co-occurrence of significant drought in adjacent water resource zones reduces the ability of water companies to transfer water between supply zones (Murgatroyd et al., 2022). There will be increasing threats from floods impacting both water supply and wastewater management. There will be ongoing threats from combined sewer overflow contamination (Adey et al., 2022; RAEng, 2024). The deterioration in water quality will increase the challenges for water treatment and ultimately water safety (Dobson et al., 2020; UKHSA, 2023).

The residual risk accounting for planned adaptations remains high. Given the increasing uncertainty in hydrology (Milly et al., 2008), the occurrence of droughts that have a magnitude greater than a 1-in-500-year event cannot be discounted. There are efforts underway to adapt water supply infrastructure to flooding, but there is limited information on flood risk management for critical points in water infrastructure, despite previous evidence of its importance (Pitt, 2007).

Whether the increasing threat of water quality deterioration will be managed is hard to assess so far in the future. Experience shows that water treatment developments can occur rapidly in response to observed threats. The current water company adaptation reports include plans for upgrading water treatment works. If a substantial programme of research is instigated, treatment improvements may keep pace with emerging challenges. The lack of actions on wildfire suggests these risks may not be well managed.

<u>2080s, central and high warming scenarios:</u>

For the scenarios in the 2080s, the risk is assessed as very high based on expert judgment. Floods, drought, wildfires, and storms are all expected to be more frequent and intense. The residual risk accounting for adaptation remains high in England, Scotland, and Wales, and for Northern Ireland is very high. While adaptation plans have been developed, it is unclear whether the actions proposed will be sufficient to cope with anticipated changes, and some risks (e.g., wildfire) have largely been ignored. There is medium confidence in the management of drought risk given the requirement, at least in England and Wales, to provide resilience up to a 1-in-500-year drought. However, severe drought and co-occurrence of drought in adjacent water resource zones may challenge the resilience of supplies.

Level of preparedness for risk

The quality of adaptation plans varies. All water companies recognise some level of risk, but strategies contain limited evidence on quantitative measures of success, or in investment strategies there is limited detail, particularly for the 2080s. Some water companies link review of adaptation plans to the periodic pricing reviews thus strategic interventions beyond the five-year period are not assured. Ofwat sets targets for water companies in England and Wales to support resilience. However, most resilience targets were missed in the 2024 pricing review, in some cases by a very considerable margin. Regulators in Scotland and Northern Ireland have not prepared similar plans, despite water companies in both nations recognising the climate risks and vulnerabilities (Boca et al., 2022; Rivington et al., 2020).

Demand management and behavioural change considerations are less clear in the adaptation plans (Xenochristou et al., 2020). Emerging risks from wildfire are poorly considered. Some water companies note these could increase peak demand, but not their impact on the catchment. Only some (e.g., Severn-Trent) set out plans for tackling these threats.

Assessment on the evidence base and evidence gaps

There remains an urgent need for more research and improved modelling of how climate changes will affect water supplies, particularly compound risks such as heavy rain events following a period of extended drought affecting both water flows and water quality. The interplay of wildfire, drought and flood risks require more integrated modelling. Consideration of complex chemical cocktails and the remobilisation of historical pollutants and their metabolites is important because the effects on human and ecosystem health remain unknown. There is a UK fire season (Perry et al., 2022), but there is a dearth of research on wildfire impacts on water supplies both in terms of single and repeated events' effects on hydrology and on water quality and supply. The adaptation plans developed by water companies across the UK lack granular detail and have limited plans for evaluation. More robust periodic quantitative evaluation of effectiveness is needed to provide greater confidence in both current adaptation plans and to ensure that there is adequate flexibility in forward planning to accommodate currently unanticipated changes. Within this, a common approach across all four nations that accounts for different models of ownership and regulatory regimes would be beneficial

6.2.9.2 England

Drought is the major climate hazard of concern in England (Dobson et al., 2020; Murgatroyd et al., 2022; Welbank, 2021), with floods an increasing threat to both water and wastewater services (RAEng, 2024). Modelling by Murgatroyd et al. (2022) concluded that resilience to a 1-in-500-year drought was achievable if identified strategic resource options are used, and abstraction of water is reduced. They note that achieving this target will be easier if more action is taken to reduce and manage demand. The southeast of England is the region most severely at risk from drought (State of the Climate Chapter).

It is unclear whether the announcements on expanded water storage in England include allocations for new water-intensive industries as well as population growth. The current and planned construction of expanded storage and inter-basin transfers and the potential for a transfer from Kielder Water to Abington has been modelled (Khadem et al., 2021). The study did not consider demand management but noted that water transfer was only feasible during winter months to avoid water shortages and ecological harm in the Kielder catchment. This raises questions about the effectiveness of current and planned measures for future water scarcity.

Evaluation of urgency score

Evidence from multiple high-quality sources along with adaptation plans and strategies prepared by water companies indicates with High confidence that climate impacts current water supply and water quality with a High magnitude risk. In the 2030 near future, risk remains High, but with Medium confidence is lower given lower levels of evidence. For the 2050s and 2080s, the severity of climate impacts (floods, droughts, water quality) will increase, exacerbated by population growth and shift, and water-intensive industries, particularly in southeast England. For 2050s, although climate risks are projected to increase, Expert judgment and available literature indicates that the level of impact will not exceed that within the High magnitude banding. For 2080s, the magnitude of impact is likely to be Very High, based largely on Expert judgment, with Low confidence. However, planned adaptation actions by water companies reduces the magnitude to High, and is associated with an increase in confidence level to Medium (as more evidence is available with which to assess this scoring).

Table 6.47: Urgency scores for I9 Risks to water supply and wastewater systems for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England								
I9	Risks to water supply and wastewater systems.							
		Present	2030		2050		2080	
			Central	High	Central	High	Low	Central	High

	Present	2030 Central	2030 High	2050 Central	2050 High	2080 Low	2080 Central	2080 High
No adaptation	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	+ (VH)	+ (VH)	+ (VH)
With adaptation	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.9.3 Northern Ireland

There is limited published literature specific to Northern Ireland, although there is good quality evidence for harmful algal blooms do occur even on large water bodies, with studies identifying algal mats containing a number of human pathogens and toxins (Reid et al., 2024). The NI Water Climate Change Strategy includes modelling of medium and high climate scenarios (RCPs 4.5 and 8.5) and evaluation of risk but lacks detail on adaptation actions and there is no investment plan. The strategy notes that this will be reviewed in subsequent pricing reviews, which adds further uncertainty as it implies some actions will be predicated on outcomes from that review. Furthermore, there was no regulator report on the performance of NI Water against previous targets indicating weaknesses in the monitoring of compliance to targets

Evaluation of urgency score

UK and Northern Ireland specific evidence indicates a High magnitude of current risk, but with a Medium level of confidence to reflect the more limited evidence base. For the 2050s and 2080s, there is limited evidence on the impact of future climate impacts. Expert judgment expects the severity of climate impacts to increase; for 2050s, the level of impact will not exceed the upper bound of the High magnitude band, but for 2080s, the magnitude of impact is likely to be Very High (Low confidence). After considering the NI Water Climate Change Strategy, no reductions in risk magnitude are made as there is no evidence for adaptation action being sufficiently effective (Expert judgment). The increased evidence raises the confidence level to Medium.

Table 6.48: Urgency scores for I9 Risks to water supply and wastewater systems for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland								
I9	Risks to water supply and wastewater systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	+ (H)	+ (H)	+ (VH)	+ (VH)	+ (VH)

With adaptation	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (VH)	++ (VH)	++ (VH)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.9.4 Scotland

Projections of hydro-hotspots (areas prone to compound flood and drought events) in Scotland highlight the critical need for more research on the effect of climate change on groundwater availability and quantity given its importance for private supplies, already at elevated risk from climate change, and irrigation (Boca et al. 2022). Also, Visser-Quinn et al., (2021) identify two hotspots of both drought and abstraction in the rivers Spey and Tay and note that by the 2080s (Central estimate), the frequency of drought events could see a two or three-fold increase with abstraction exacerbating the pressure to water supplies. Moreover, extreme meteorological drought events may increase in frequency from an average of one event every 20 years (current day) to one event every 3 years by 2040.

Private water supplies, which serve 3.6% of the population in Scotland, are particularly exposed to water scarcity as there is limited redundancy in the supply system. A key challenge for Scotland is the national messaging around climate change impacts to water resources, and future increasing water scarcity (McClymont and Beevers, 2022).

Evaluation of urgency score

Evidence from multiple high-quality sources along with adaptation plans and strategies prepared by water companies indicates with High confidence that climate impacts current water supply and water quality with a High magnitude risk. In the 2030 near future, risk remains High, but with Medium confidence is lower given lower levels of evidence. For the 2050s and 2080s, the severity of climate impacts (floods, droughts, water quality) will increase, particularly in hotspots noted above. For 2050s, although climate risks are projected to increase, Expert judgment and available literature indicates that the level of impact will remain in the High magnitude band. For 2080s, the magnitude of impact is likely to be Very High based largely on Expert judgment with some information on specific risks and regions (Visser-Quinn et al., 2021), with Low confidence. However, planned adaptation actions by water companies reduces the magnitude to High, and is associated with an increase in confidence level to Medium (as more evidence is available with which to assess this scoring).

Table 6.49: Urgency scores for I9 Risks to water supply and wastewater systems for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland	
I9	Risks to water supply and wastewater systems.

	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	+ (VH)	+ (VH)	+ (VH)
With adaptation	+++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.9.5 Wales

Dallison et al. (2021) report that, for their study of two catchments in Wales under a range of climate scenarios, streamflow decrease would result in unmet demand in absence of upstream reservoirs with problems greater in near term. As noted above, water companies in Wales (and England) are required to ensure resilience up to a 1-in-500-year drought.

Evaluation of urgency score

UK level evidence, combined with evidence from Wales, indicates a High magnitude of current risk, but with a Medium level of confidence to reflect the more limited evidence base. For the 2030s the urgency score will be similar to present day. For the 2050s and 2080s, there is Medium confidence that the severity of climate impacts (floods, droughts, water quality) will increase; for the 2050s, evidence and Expert judgment indicates this will not exceed the High magnitude banding (Medium confidence). For 2080s, the magnitude of climate impacts is likely to be Very High, based largely on Expert judgment. However, planned adaptation actions by water companies reduces the magnitude to High, and is associated with an increase in confidence level to Medium (as more evidence is available with which to assess this scoring).

Table 6.50: Urgency scores for I9 Risks to water supply and wastewater systems for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales								
I9	Risks to water supply and wastewater systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	+ (VH)	+ (VH)	+ (VH)

With adaptation	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)	++ (H)
Urgency scores	MAN	MAN		MAN			MAN	
Overall urgency score	MAN							

6.2.10 Risks to waste management systems, excluding wastewater systems – I10

Waste management systems (excluding wastewater systems), here referred to as waste infrastructure, include: (i) nuclear, i.e., nuclear waste and decommissioned /decommissioning power station sites; (ii) mining and extraction, specifically coal spoil tips; and, (iii) general waste management, i.e., landfill sites (active and historic), waste incinerators, thermal treatment plants, household waste recycling centres, transfer stations, and material recovery facilities.

Headlines

- "Further investigation" is the urgency score for England, Scotland, and Northern Ireland which primarily concerns landfill (existing and historical), and nuclear (waste and decommissioned/decommissioning sites).
- In Wales, the score is "Critical Investigation", due to additional risks regarding slope failure in coal spoil tips, particularly following heavy rainfall events and storms.
- For most of the sector, the risk of damage and disruption on an annual basis is likely to be low and any impacts are likely to be localised. Risk in Wales is anticipated to reduce as policy addresses risk from coal spoil tip failure.
- There is no indication that risk will increase or decrease as compared to present day. Expert judgement considers the risks unlikely to significantly increase.
- The literature on climate impacts and adaptation progress is limited. There is a lack of coordination across the sector to fully understand and respond to risks.

Table 6.51: Urgency scores for I10 Risks to waste management systems, excluding wastewater systems. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

ID	Risk		Present	2030	2050	2080	Urgency
I10	Risks to waste management systems, excluding wastewater systems	**UK**	+ (H)	+ (M)	+ (M)	+ (M)	CI
		England	+ (L)	+ (L)	+ (L)	+ (L)	FI
		Northern Ireland	+ (L)	+ (L)	+ (L)	+ (L)	FI

		Scotland	+ (L)	+ (L)	+ (L)	+ (L)	FI
		Wales	+ (H)	+ (M)	+ (M)	+ (M)	CI

6.2.10.1 Evidence relevant to the entire United Kingdom

Current and future drivers of risk

The evidence of climate impacts on waste infrastructure is limited. Concerning nuclear, there are no reports of current or future impacts from extreme weather or sea level rise on infrastructure or operations. The Nuclear Decommissioning Authority (NDA) estate has 17 sites across Great Britian that are planned for or undergoing decommissioning, most which are near the coast. Each site complies with safety assessment principles for nuclear facilities, which include consideration of extreme weather and climate change (NDA, 2020) and periodic safety reviews every 10 years. Although decommissioning will lead to fewer active sites, nuclear waste will need to be managed into the future.

Waste disposal sites were historically located in coastal areas close to industrial and commercial sites. In some locations, erosion has released landfill waste onto the beaches and waters (BBC, 2024g), and land, subtidal, and intertidal sediments may be contaminated from landfill and other historical unmanaged waste disposal (Bardos et al., 2020). Where these sites are exposed to increased erosion due to sea-level rise or coastal flooding and storm surges, the level of impact is expected to remain the same or increase. Active, closed, and historic landfills can release hazardous substances into the environment following floods or drought (Environment Agency, 2023b; Brand and Spencer, 2024; Weber et al., 2025), although highly developed flood-prone areas typically have extensive defences in place to lower risk (Nicholls et al., 2021). Future warmer summer temperatures could lead to an increase in hot waste, such as barbeque disposal, which can lead to waste fires (Environment Agency, 2023b). Wildfires may also be exacerbated or intensified if landfill sites are nearby due to them being a significant combustion source (Ibrahim et al., 2020). There are no reports of climate impacts on household recycling centres, waste incinerators (including those for energy generation), or other waste infrastructure. Local authority ARP reports include risks to waste collections services or waste disposal infrastructure caused by extreme weather (Blackpool), potential impacts on waste collections teams working outdoors (Colchester), and climate impacts on roads impacting waste collection (Warwickshire).

Waste infrastructure is changing; waste to landfill is decreasing, recycling and Waste to Energy generation is increasing (DEFRA, 2025). Future population growth may increase waste generation, but this increase could be offset by increased waste recycling or waste prevention. These changes will change the location and amount of waste infrastructure and the sector’s exposure to climate risk. Whether risk increases will depend on what infrastructure is needed, where it is located, and whether it is designed for future weather and climate. Local vulnerabilities, such as prioritised collection for medical waste customers, should also be considered.

A tipping point regarding waste infrastructure would be extreme sea level rise, e.g., the complete loss of ice sheets. Sea level rise that completely inundates low-lying coastal sites (e.g., nuclear waste treatment and storage infrastructure) could have substantial human and environmental impacts, given that the infrastructure is likely to exist beyond 2100. Coastal landfill sites could also be impacted in a similar way.

Assessment of current magnitude of risk

The current magnitude of risk for waste infrastructure is considered Low. There are no reported impacts from the nuclear sector. Excepting Wales there are no reported impacts from mining and extraction waste (see Section 6.2.10.5). Climate impacts on waste infrastructure such as erosion of historic landfill sites are reported, but local in scale.

Assessment of future magnitude of risk

Risk from current and future extreme weather and climate is routinely considered under the robust safety principles outlined by the Nuclear Decommissioning Authority (NDA, 2020) so this risk is unlikely to increase. Some academic studies consider future climate risks to waste infrastructure, such as:

- Future changes in temperature, groundwater chemistry, flow rates, and sea salinity on geological repositories for nuclear waste are implied (Pizarro and Sainsbury, 2023),
- Coastal erosion and flooding of landfills, and the need for further analysis to understand future change in geomorphology and the local-level impacts on sites (Nicholls et al., 2021),
- The future erosion and release of solid waste considered more of a threat than flooding and leachate release from landfills (Beaven et al., 2020).

There are no studies that quantify the climate impacts on waste infrastructure for specific time periods or climate. Expert judgment discusses these qualitatively below.

<u>2030s, central warming scenario:</u>

In the near-term, climate risks may be similar, albeit with some shifts in intensity. However, the waste infrastructure landscape is likely to be similar to present, with a small potential increase in risk in locations where population growth demands an increase in waste facilities. Erosion of costal landfill sites is likely to continue without remediation. As such, any climate impacts are likely to be local in scale, and the magnitude of risk is likely to overall remain similar to the present day, i.e., Low in England, Scotland, and Northen Ireland, but High in Wales due to the potential for coal tip failures (See Section 6.2.10.5). Confidence is Low given the limited evidence.

<u>2050s, central and high warming scenarios:</u>

In the 2050s, the frequency and magnitude of heavy rainfall events and hot summer temperatures will increase. Heavier rainfall may lead to flooding, and in coastal areas this may be exacerbated by sea level rise, which may increase erosion of historic landfill sites where defences are currently insufficient (BBC, 2024g). Heavier rainfall will increase the potential for coal tip landslides in Wales. High temperature events, especially those coupled with periods of drought, may lead to wildfires at landfills or wildfires being exacerbated by nearby combustive waste. Nuclear decommissioning will be continuing, but safety principles are anticipated to mitigate climate impact. Waste reduction initiatives should be well established in reducing landfilling, although population growth may increase waste streams and recycling, as well as more legacy landfills to manage. New municipal waste sites should have been built with climate risk, particularly flooding in mind; older sites may continue to be protected by existing defences. It is likely that extreme weather and costal erosion will impact existing and future waste infrastructure, and risk may increase as climate events increase in frequency and magnitude. However, impacts are expected to be localised and Low magnitude (see Section 6.2.10.5 for mining waste in Wales). Confidence is Low given the limited evidence.

<u>2080s, central and high warming scenarios:</u>

In the 2080s, the frequency and magnitude of heavy rainfall events and hot summer temperatures is likely to have increased since the 2050s. Heavier rainfall may lead to flooding, and in coastal areas this may be exacerbated by far higher levels of sea level rise. High temperature events, especially those coupled with periods of drought may lead to wildfires at landfills, or wildfires being exacerbated by nearby combustive waste. Nuclear decommissioning will be continuing. Historic landfill sites will remain, but waste management and infrastructure are expected to have changed significantly from present day. New infrastructure should have been designed with climate change in mind given the anticipated increase in adaptive capacity across with time. As per previous time periods, any impacts on waste infrastructure (excepting coal tip failures) is likely to be local in scale and Low magnitude. Confidence is Low given the limited evidence.

Level of preparedness for risk

The nuclear sector has robust safety principles that prepare for a range of risks, including those from extreme weather and climate (NDA, 2020). Other waste infrastructure is typically the responsibility of local authorities, who develop their own strategy for their region, and waste management authorities, who are responsible for their own assets. Historically, local authority climate adaptation has lagged some national infrastructure providers; however, 11 local authorities contributed to the ARP process for the first time in 2024 and three local authorities mentioned climate risks, with two providing high-level adaptation actions (Blackpool, Warwickshire). Waste infrastructure facilities are required to adhere to national planning frameworks within the devolved nations. Regulation of waste is devolved by nation. The UK Government provides guidance on integrating climate change adaptation into management under an environmental permit (as part of the system for England; although the guidelines are relevant UK-wide), but uptake and oversight of this in any nation is unclear. In general, most of the climate risk for this sector is UK-wide, and therefore the devolved nations will experience similar current and future drivers of risk; current and future magnitude of risk; and levels of preparedness of risk. However, it is important to note that site-specific factors are what drive key vulnerabilities across the sector (Environment Agency, 2023c).

Assessment on the evidence base and evidence gaps

Evidence is limited in comparison to other infrastructure sectors. Waste infrastructure owners and operators were not invited to submit to the ARP process and have not done so. However, high-level information on climate risks to waste is mentioned in three local authority adaptation plans. Academic peer review papers tend to focus on flood risk or coastal erosion to landfills (e.g., Brand and Spencer, 2024; Nicholls et al., 2021). Waste statistics are available online (DEFRA, 2025), but these do not include climate risks. Information on nuclear safety is available from the NDA (2020), and Pizarro and Sainsbury (2023) identified evidence gaps on local climate vulnerability assessment for nuclear power plants, climate adaptation for spent fuel storage (e.g., on-site and centralised facilities, and climate adaptation measures for long-term storage or final repositories).

6.2.10.2 England

There are currently just over 500 operational landfills across England (Environment Agency, 2025). Since 2023, England is the only devolved nation where climate change adaptation is considered as part of waste permit applications (Environment Agency, 2023c).

There are over 20,000 closed or historic landfills in England (UKHSA, 2024), and nearly 4,000 of these do not have flood defences and are located within areas where there is greater than 1% annual probability of fluvial flooding and/or greater than 0.5% annual probability of flooding from the sea. However, highly developed flood-prone areas like the Thames Estuary have high and extensive defences in place, protecting most landfills (and presumably, other waste infrastructure) within the protected area (Nicholls et al., 2021).

Any new waste facilities are required to adhere to the National Planning Policy Framework (MHCLG, 2024), which states that development should be avoided in areas of highest flood risk and that development should consider climate risk.

There are 11 nuclear decommissioning sites in England (of 17 total for the UK), so the country has comparatively greater exposure. However, no near-term impacts are reported – the main concern is regarding Sellafield (where, if existing coastal defences are not maintained, the southern end of the site may be vulnerable in the next 100 years). Most coal spoil tips in England are located across the West Midlands and the Northwest, although there is no central record of the locations of all these in England (DESNZ, 2024b). The Mining Remediation Authority inspects seven of these sites (MRA, 2024). There are no recent reports of landslips due to flooding or heavy rainfall located around coal spoil tips in England.

Evaluation of urgency score

The available evidence indicates that any climate impacts are likely to be local in scale, therefore Low magnitude. In the 2030s, the sector landscape and present-day weather-related impacts are likely to be similar. In the 2050s and 2080s, although the issues related to historic landfills are likely to continue, new waste infrastructure is likely to be different to present day. Climate risks may increase as climate change intensifies, but newer waste infrastructure should be designed with climate change in mind, and impacts are still likely to be local in scale. Confidence is Low, and scoring relies predominantly on Expert judgment.

Table 6.52: Urgency scores for I10 Risks to waste management systems, excluding wastewater systems for England. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

England								
I10	Risks to waste management systems, excluding wastewater systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)
With adaptation	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)
Urgency scores	FI	FI		WB			WB	
Overall urgency score	FI							

6.2.10.3 Northern Ireland

There currently 38 permitted landfills in Northern Ireland (Department of Finance, 2023). There is no nuclear infrastructure in Northern Ireland. There is no information on coal spoil tips (as the Mining Remediation Authority does not cover Northern Ireland), though abandoned mines are monitored by the Department for the Economy. Potential climate impacts related to household waste infrastructure are likely to be similar to those outlined for the UK, such as localised pollution following flooding or erosion of landfill site, or disruption to waste management processes due to extreme weather that temporarily prevents operations. The Strategic Planning Policy Statement (Department of the Environment, 2015) specifies that development should be avoided in areas vulnerable to the effects of climate change.

Evaluation of urgency score

The available evidence indicates that any climate impacts are likely to be local in scale, therefore Low magnitude. In the 2030s, the sector landscape and present-day weather-related impacts are likely to be similar. In the 2050s and 2080s, although the issues related to historic landfills are likely to continue, new waste infrastructure is likely to be different to present day. Climate risks may increase as climate change intensifies, but newer waste infrastructure should be designed with climate change in mind, and impacts are still likely to be local in scale. Confidence is Low, and scoring relies predominantly on Expert judgment.

Table 6.53: Urgency scores for I10 Risks to waste management systems, excluding wastewater systems for Northern Ireland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Northern Ireland								
I10	Risks to waste management systems, excluding wastewater systems.							
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)
With adaptation	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)
Urgency scores	FI	FI		WB			WB	
Overall urgency score	FI							

6.2.10.4 Scotland

Scotland has 41 permitted landfill sites (SEPA, 2024). There are three nuclear decommissioning sites, of which only Hunterston A is viewed as vulnerable to the effects of climate change; its only access road requires management attention due to projected coastal erosion (NDA, 2020). There are fewer coal spoil tips than England and Wales although there is no central record of them all in Scotland (DESNZ, 2024b). Five tips are inspected by the Mining Remediation Authority (MRA, 2024). Under the National Planning Framework, new waste infrastructure in Scotland must take climate risks into account (Scottish Government, 2023) and there is specific planning guidance for climate adaptation (Scottish Government, 2025).

Evaluation of urgency score

The available evidence indicates that any climate impacts are likely to be local in scale, therefore Low magnitude. In the 2030s, the sector landscape and present-day weather-related impacts are likely to be similar. In the 2050s and 2080s, although the issues related to historic landfills are likely to continue, new waste infrastructure is likely to be different to present day. Climate risks may increase as climate change intensifies, but newer waste infrastructure should be designed with climate change in mind, and impacts are still likely to be local in scale. Confidence is Low, and scoring relies predominantly on Expert judgment.

Table 6.54: Urgency scores for I10 Risks to waste management systems, excluding wastewater systems for Scotland. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Scotland								
I10 Risks to waste management systems, excluding wastewater systems.								
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)
With adaptation	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)	+ (L)
Urgency scores	FI	FI		WB			WB	
Overall urgency score	FI							

6.2.10.5 Wales

In Wales, the risk associated with coal mine tips (see next paragraph) is high and consequently increases the overall magnitude of risk for Wales to High (with no additional adaptation). There are approximately 20 operational landfills in Wales (Natural Resources Wales, 2024). While there are fewer active and historic landfills than England, many historic landfills in Wales are in coastal zones, and six of these may become exposed and a potential source of pollution at the current erosion rates in future without defences in place (Irfan et al., 2019). There are also two nuclear decommissioning sites, neither of which report any high risk to flooding.

Coal spoil tip collapses are more prevalent in Wales. Landslides can occur in these locations when the water table rises following heavy rain (He et al., 2024). There are over 5,000 coal spoil tips in the UK; 2,573 of these are in Wales (Welsh Government, 2024b). Of these, 327 are considered high risk, meaning that they could endanger life or property (Ground Engineering, 2022). More coal spoil tips are inspected by the Mining Remediation Authority in Wales (24) than in other devolved nations (MRA, 2024). However, many tips are otherwise privately or commercially owned (BBC, 2023) but the MRA can provide inspection and management services for these. The Welsh Government estimates that the cost of managing coal spoil tips in Wales could be around £500m over the next decade (Ground Engineering, 2022).

The Government response to coal spoil tip risk may reduce risk in the future. In 2020, extreme rainfall in South Wales led to a coal spoil tip landslip. While no homes were destroyed or lost, the landslip blocked the river, buried a water main, and broke a sewer (Law Commission, 2022). This led to a review of coal spoil tip safety law, resulting in the Disused Mine and Quarry Tips (Wales) Bill, introduced in 2024 (Welsh Government, 2024c). The bill proposes a new public body, the Disused Tip Authority for Wales, aiming to prevent coal spoil tips through assessment, registration, monitoring, and management. This additional adaptation would reduce risk, and therefore future magnitude scores for Wales are Medium, rather than high, when this proposed future adaptation is included.

Evaluation of urgency score

The risk of coal spoil tip slope failure due to heavy rain and storms is considered High magnitude for the present day, and the 2030s, where extreme weather is considered similar to present day. In the 2050s and 2080s, heavy rainfall events are expected to increase, increasing climate risk, however the scale of the impacts is not sufficient to move into the Very High banding. After considering the adaptation policies in place, risk magnitude is reduced to Medium. The impacts from other waste infrastructure are likely to be local in scale (e.g., local scale pollution following coastal erosion of landfill site) for all time periods, not changing the magnitude score. Confidence is Low, and scoring relies predominantly on Expert judgment.

Table 6.55: Urgency scores for I10 Risks to waste management systems, excluding wastewater systems for Wales. Key to the magnitude scores: very light purple (L) = Low, light purple (M) = Medium, purple (H) = High, dark purple (VH) = Very High. Key to the confidence scores: + = Low, ++ = Medium, +++ High. Where urgency scores are represented by: CAN = Critical Action Needed, CI = Critical Investigation, MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action, WB = Watching Brief. Details of how the scores in this table were calculated are in the Methods Chapter.

Wales								
I10 Risks to waste management systems, excluding wastewater systems.								
	Present	2030		2050		2080		
		Central	High	Central	High	Low	Central	High
No adaptation	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)	+ (H)
With adaptation	+ (H)	+ (M)	+ (M)	+ (M)	+ (M)	+ (M)	+ (M)	+ (M)
Urgency scores	CI	FI		FI			FI	
Overall urgency score	CI							

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