ARUP

Department for Transport

TTWO0214 – Review of Tools, Mechanisms and Guidance for Climate Risk Assessments

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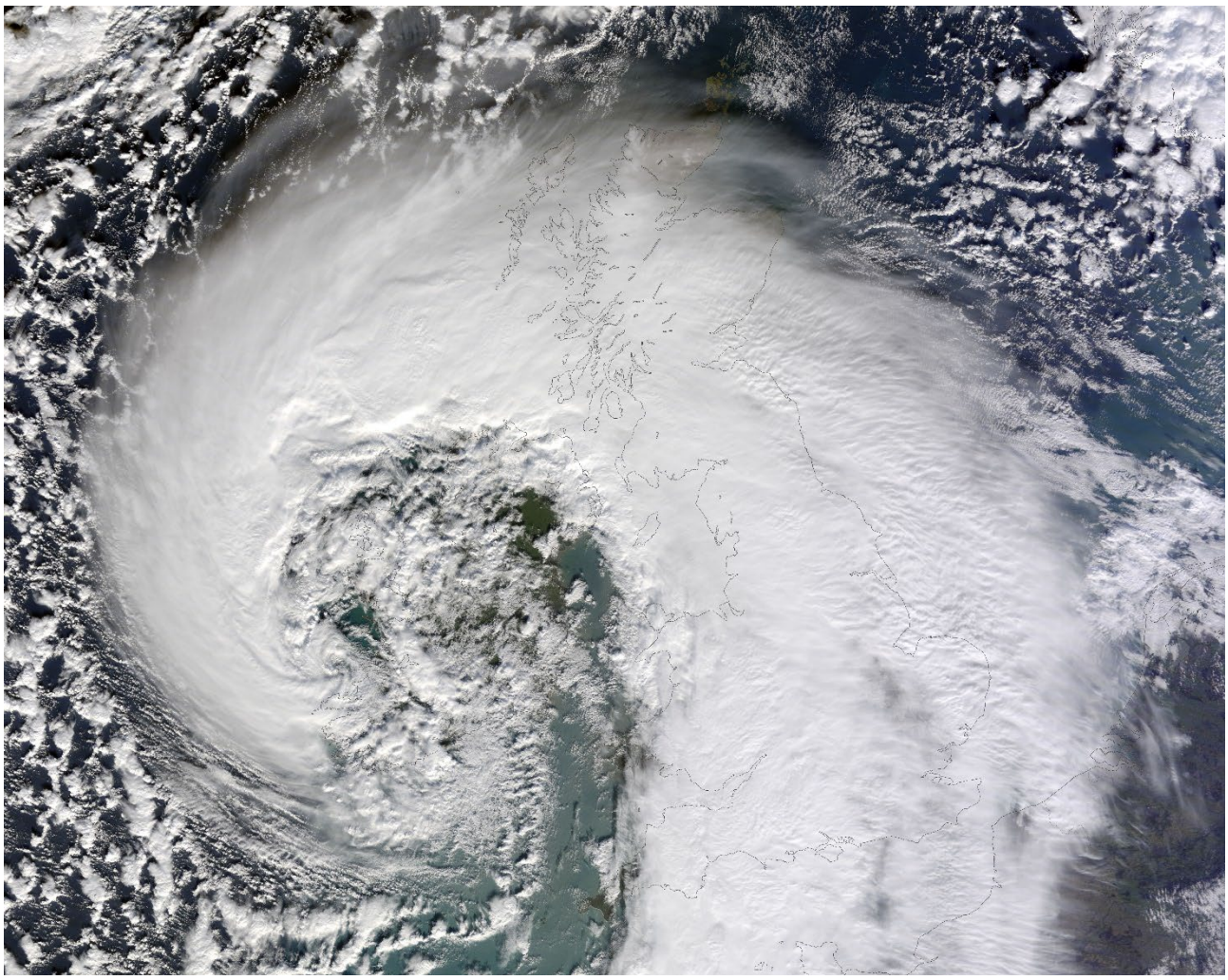

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Executive Summary

Climate change is already affecting many weather and climate extremes across the globe (IPCC, 2023), **and being felt throughout the transport sector in the United Kingdom** (Climate Change Committee, 2023). Severe weather impacts across the UK are on the rise. Growing awareness of the potential disruption, cost, as well as reliability and safety impacts of climate change has led to a need to consider climate change risks thoroughly. To do this, the right tools, mechanisms and guidance to carry out climate change risk assessments, and the knowledge of how to use and interpret the findings, should be in place. This is needed across the transport sector to inform plans for climate adaptation and resilience. In response to this need, the **Department for Transport has commissioned a study to investigate the current landscape. Our aim is to identify the potential tools, mechanisms and guidance currently available**, and used by, all parts of the UK transport sector in assessing and confronting the risks from climate change to transport infrastructure and operations.

A study, which included **a desktop literature review, a survey, and a workshop with stakeholders** from across the transport sector, was carried out. Information on 53 tools, mechanisms, and guidance items that could potentially support climate risk assessment in the transport sector in the UK have been identified. Each tool, mechanism and guidance collated during the desktop study was classified and evaluated based on four key areas including general details (e.g., year of launch), climate data and uncertainty (e.g., type of climate data used), applicability e.g. (intended scale of use, type of output) and assessment type (e.g., hazard, vulnerability).

There is no one tool, guidance, or mechanism that is considered perfectly suited to every situation, organisation, or individual's needs. However, **there are examples of good practice,** and it is possible to recommend items that will be potentially useful for different scenarios or components of the climate change risk assessment process. This report shares recommendations for users at different stages and levels of maturity, including the following options:

- In the early stages of a project considering climate risks, PCRAM, UKCIP's Adaptation wizard, UK Climate Resilience Programme's Climate Risk Indicators platform, the National Trust Climate Hazards platform and The Forestry Commission and Forest Research's climate matching tool are all useful.
- The Met Office UKCP18 data platform remains the primary source for acquiring climate projection data for the UK.
- Vulnerability and exposure are both likely to be highly specific to the details of the given asset or system being assessed. The BACLIAT vulnerability assessment process however, included as part of the UKCIP's Adaptation Wizard, is an option for those approaching vulnerability assessments at an organisational level rather than an asset level.
- Criticality assessments are also largely dependent on asset data. Most identified tools are commercial or restricted. The Open Climate Impacts modelling framework (OpenCLIM), currently under development shows promise in this area, particularly in assessing how transport systems interact with the wider infrastructure systems of the UK.
- ISO14090 is gaining traction as 'the' top level adaptation standard and covers the full process of managing climate risk, including adaptive capacity assessment, at a high level.

Many gaps were identified across the transport sector, including that many in the transport sector reported feeling overwhelmed by the existing landscape of tools, mechanisms, and guidance. **Key recommendations** for the Department for Transport to enable effective climate risk assessments include:

- **Direct transport organisations to quality existing tools,** mechanisms and guidance, to raise awareness of good practice and to cut down on confusion in a cluttered landscape.
- **Recommend an industry-wide, good practice high-level approach to climate risk assessment**, either from existing resources or by compiling a new good-practice document.
- **Continue to facilitate meetings within and across the transport sector**, with a focus on ports, airports, and local authorities' highways departments due to their potentially greater division. Encourage sharing of knowledge and approaches, and cross-transport industry interaction.
- Create a tool or easy to follow procedure for applying UKCP18 data, particularly to derive hazard frequency data. Much of this information is already available, but users are unclear on how to access it.

1. Introduction

Climate change is increasingly being felt across the world (IPCC, 2023), and throughout the transport sector in the UK. Severe weather impacts are on the rise, from the 2022 heatwave which cost Transport for London £8 million in lost revenue (Transport for London, 2023) to winter storms in 2015-16 which caused much disruption and an estimated cost of £121 million to the rail network and £220 million to the road network (Climate Change Committee, 2023). Additionally, the need to decarbonise infrastructure presents numerous transition risks to transport, as new technologies and practices must rapidly be adopted.

These events, alongside a growing awareness of the disruption caused by climate change, have led to a need to consider climate risks thoroughly. To do this, the right tools, mechanisms and guidance to carry out climate change risk assessments, and knowledge of how to use them should be in place across the transport sector.

Figure 1. Climate related hazards impacting transport networks across the UK in recent years. Severely flooded roads in Oxford (top left), high temperatures at Belfast City Airport (top right), storm surge at Port William harbour (bottom left), and repairs to the railway at Dawlish following a storm (bottom right).

1.1 Aims and Objectives

In response to this need, the Department for Transport has commissioned a study to investigate the current landscape with the following aims and objectives:

- Identify the potential tools, mechanisms and guidance currently available, and used by, all parts of the UK transport sector in assessing and confronting the risks from climate change to transport infrastructure and operations.
- Gather, review and summarise evidence and expert opinion on the current tools, mechanisms and guidance the transport sector uses to assess the risks of climate change on transport infrastructure and operations.
- Engage with key stakeholders within the transport sector and collate and review feedback on their needs.
- Apply key focus on the tools, mechanisms and guidance used to assess climate change risk in the port, local highways and airport transport sector.
- Comprehend and record where there are gaps in the current tools, mechanisms and guidance available to the transport sector and operations, hence ensure the report informs internal thinking and highlights where Department for Transport can add value.
- Present a comprehensive report detailing the findings of the review and assessment of the tools, mechanisms, and guidance. This should consider the effectiveness of the tools in risk severity analysis, prioritisation, and informing decision making to mitigate those risks. Subsequently provide a range of recommendations of the best methods on assessing the risks to their operations.

1.2 Methodology

The study included a desktop literature review, a survey, and a workshop with stakeholders from across the transport sector, prior to the creation of this report. The details of each are given below.

1.2.1 Desktop Study

A thorough desktop study was undertaken to identify the potential tools, mechanisms and guidance used by the UK transport sector. This entailed research of trusted public sources including transport organisations that report under the Adaptation Reporting Power and professional and public bodies (e.g., the Climate Change Committee).

A classification system of properties was developed and used to determine the efficacy and relevance of each tool, mechanism and guidance collated in the desktop study and was subsequently used to create a comprehensive list of tools, mechanisms and guidance that could be used in the UK transport sector. The characteristics included the working definitions of each tool, mechanism and guidance, the relevant sector, system, type of resilience addressed and the complexity of each output. Internal organisational approaches or generic approaches were omitted from the master compilation.

1.2.2 Survey

The information collated from this exercise was used to shape a detailed survey given to stakeholders from the transport sector, a list of organisations surveyed is included in Appendix A. Some key survey questions included:

- What is the functionality of the climate risk assessment tools, mechanisms and guidance your organisation currently uses?
- Does your organisation need tools/guidance for ongoing use?
- What are the limitations of current tools, mechanisms and guidance?

1.2.3 Workshop

An interactive online workshop was held for representatives from each transport sector as part of stakeholder engagement. A summary of the tools, mechanisms, and guidance collated from the primary desktop study was shared with the attendees to enable the missing tools, possible connections, and similarities to be easily identified and recorded. The wider group feedback was recorded and used to evaluate the initial desktop research compilation and classification applied. Attendees were also separated into sector specific breakout rooms chaired by Arup subject matter experts, where in-depth analysis and feedback of the tools, mechanisms and guidance initially presented from the desktop study was discussed as well as additional tools used in industry. All stakeholder input was converted into useful data and information, additional tools in particular were recorded and evaluated using the classification system. See Appendix A for the organisations included.

1.2.4 Report

This report provides a concise summary of each stage of the project the desktop study, survey and workshop, and provides final findings, gaps, and recommendations.

1.3 Classification and Evaluation System

Each tool, mechanism and guidance collated during the desktop study was classified and evaluated based on four key areas. The full explanation and working definitions in the taxonomy are in Appendix B. The four areas were:

General – tools, mechanisms and guidance were classified based on the relevant transport sector, year of launch and level of access (open/restricted).

Climate Data and Uncertainty – The type of climate data used in each tool, mechanism and guidance was assessed by evaluating the number of emissions/climate scenarios used as well as the respective maximum applicable assessment year.

Applicability – To ascertain the applicability of each tool, mechanism and guidance in practice, the outputs were evaluated to identify the applicable lifecycle stage, the intended scale of use (e.g. asset or network), the type of output provided, the CCRA3 Key Risks assessed, whether it was was currently in use in the UK transport sector and whether it was appropriate for one-time or ongoing usage.

Assessment Type – The tools, mechanisms and guidance were evaluated based on the type of assessment and output. The type of assessments entailed: hazard, vulnerability, criticality/consequence, adaptive capacity and cost-benefit analysis. The items were also evaluated in terms of the complexity of the output and the delivery level (i.e. the extent to which the given item delivers the output). A detailed definition for each evaluation criterion can be found in the taxonomy in appendix A.

The risk assessment process, as understood in this study, is summarised in Figure 2. This process is modelled on the Green Book supplementary guidance (Defra, 2020) with some minor modifications. Criticality is added, due to its high importance to the overall impact of events on interconnected networks, such as transport systems. Additionally, adaptive capacity is listed here as part of options assessment. It should be noted that assessment of existing adaptive capacity can also feed into risk assessment, acting to counteract vulnerability. The IPCC uses a similar risk assessment process, with some minor differences in terminology.

As defined in Figure 2, exposure assessment primarily depends on combining asset inventory information with location-specific hazard data. Asset inventory information is also a valuable input for vulnerability and criticality assessment; however, it is part of wider asset management considerations and falls outside the scope of this review. Useful resources on the subject are provided by the Institute of Asset Management, including their Asset Management – An Anatomy (Institute of Asset Management, 2015). This review does not therefore include tools, mechanisms, and guidance specific to exposure, however hazard assessments providing spatial information that can support exposure assessment are highlighted.

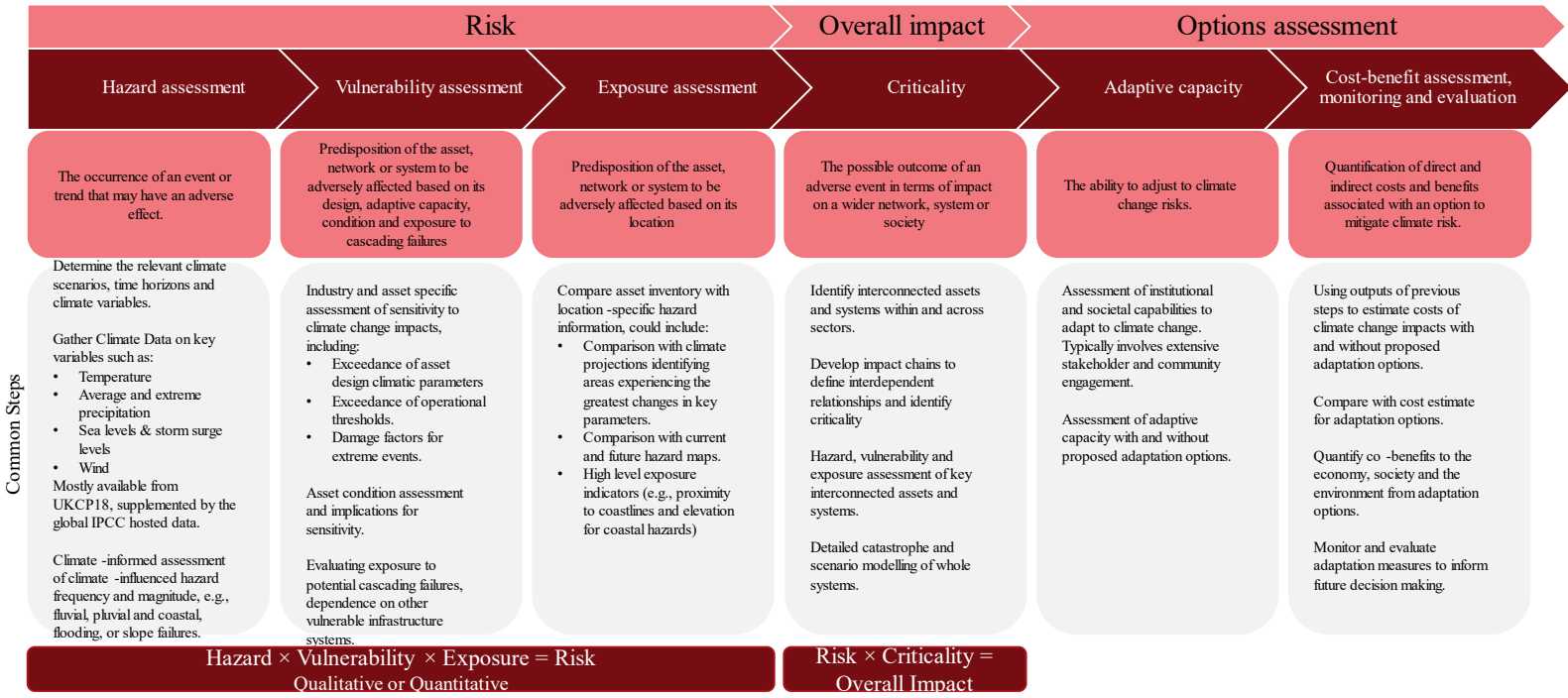

Figure 1. Generalised risk assessment process and steps.

2. Collated Tools, Mechanisms, and Guidance

2.1 Applicability and Assessment Types

This review has identified a total of 53 tools, mechanisms, and guidance items that could potentially support climate risk assessment in the transport sector. As shown in Figure 3, most of these tools, mechanisms and guidance (70% of the total) are cross-sector, and could be applied equally to any infrastructure sector. The remaining items are split evenly between sectors within transport, with slightly more port items, and fewer aviation items. Most of the items are also open access, however commercial and restricted options become more prevalent when examining the sector-specific items, particularly in the road and rail sectors.

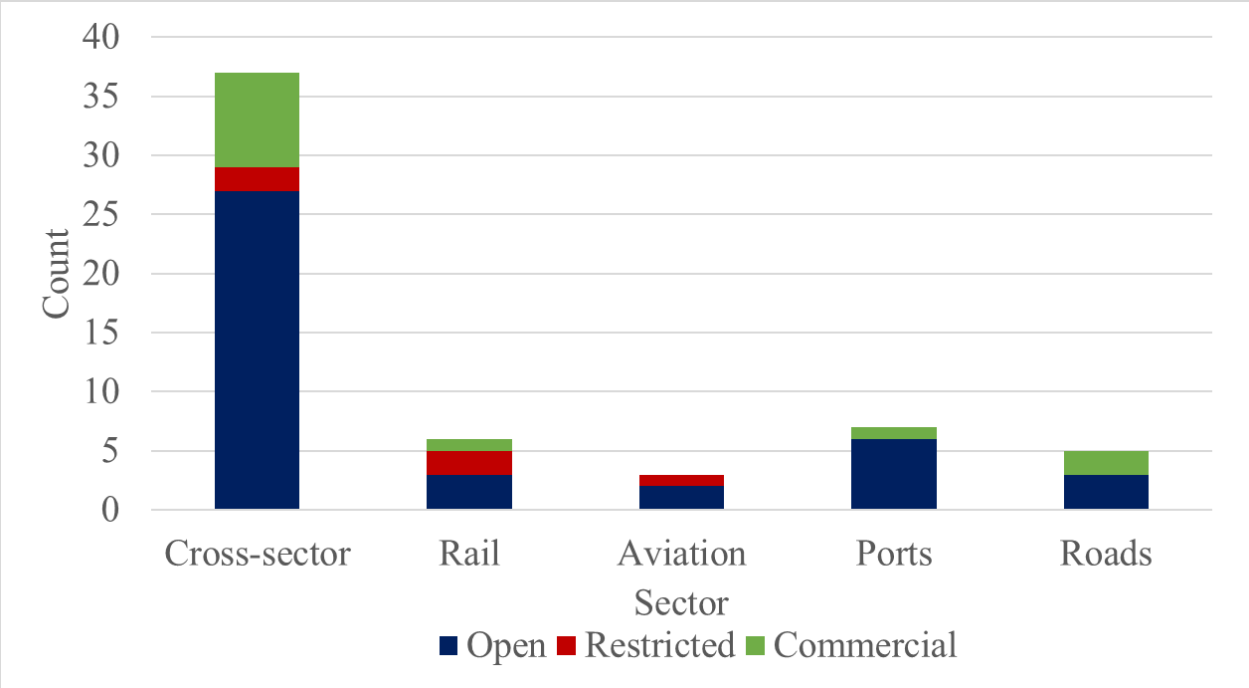

Figure 3. Counts of open, restricted, and commercial access items assessed by sector.

This trend of general applicability continues in other areas. In terms of the infrastructure lifecycle, 70% of the total assessed tools, mechanisms and guidance were found to have no clear applicability to a specific lifecycle stage. Of the items that were geared towards a specific lifecycle stage, they were distributed between early-stage planning, policies and prioritisation, risk assessment as part of financing decision-making, and operations & maintenance. Similarly, based on comparison against the UK's 3rd Climate Change Risk Assessment (CCRA3) key risks to transport infrastructure, the majority (64% of the total) of items were suitable for generic risk assessment, rather than being targeted at specific risk areas.

In terms of assessment areas covered by the identified items, the most common assessments focused on hazard, followed by vulnerability (see Figure 4). Whereas criticality and consequence assessments were around half to a third as common. This is unsurprising, as vulnerability and hazard are typically considered to form the core of a risk assessment alongside exposure. Additionally, a little under half of tools, mechanisms, and guidance for hazard assessment directly facilitate spatial hazard assessment (through the provision of spatial climate projection or hazard data or maps), therefore supporting a key component of exposure assessment. As previously noted, the other component of exposure assessment, asset inventory data, is out of scope for this review.

Fewer items have been assessed that deliver cost-benefit and adaptive capacity assessments, these were not the primary focus of this review, and so may not necessarily reflect a gap overall. However, in the context of climate risk assessment, both assessment types could be seen as supporting the value judgement for mitigative action. The greater prevalence of cost-benefit assessment over adaptive capacity could indicate that industry focus has traditionally been on minimising financial impacts, rather than considering wider implications for organisational or societal resilience. Climate change mitigation, adaptation and resilience are by comparison newer considerations for transport sector projections, and therefore relatively fewer tools, mechanisms and guidance currently exist.

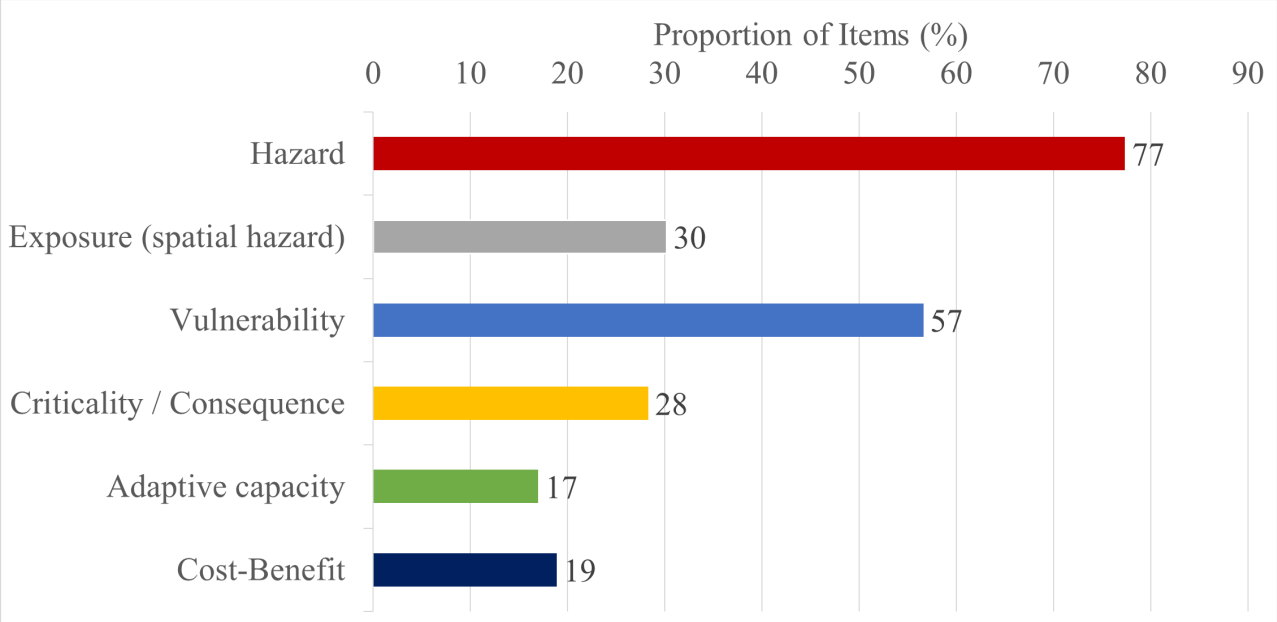

Figure 4. The proportion of items that can be applied to support each assessment category.

As part of our review, we assessed each item in terms of the complexity of its risk assessment output, and the extent to which the item delivers this output directly versus requiring the user to do their own work. Based on this categorisation, almost all the identified items fall into three primary groups: tools directly providing climate projection data or simple assessment of climate hazard and impacts; items that provide high level recommendations or procedures to conduct low to mid-complexity climate risk assessments, this is the largest group; and high complexity, typically commercial, tools to deliver advanced risk assessments, the smallest group of the three.

2.2 Reported Usage of Climate Change Tools, Mechanisms and Guidance

Of the 53 identified items, 48 were found to have at least nominal usage in the UK transport industry based on the workshop and external research. However, most items had only limited reported usage. Of the 40 items presented to the workshop participants, 33 items were used by less than a quarter of respondents, and the average tool was used by 14% of respondents. Figure 5 shows the items with the greatest reported usage.

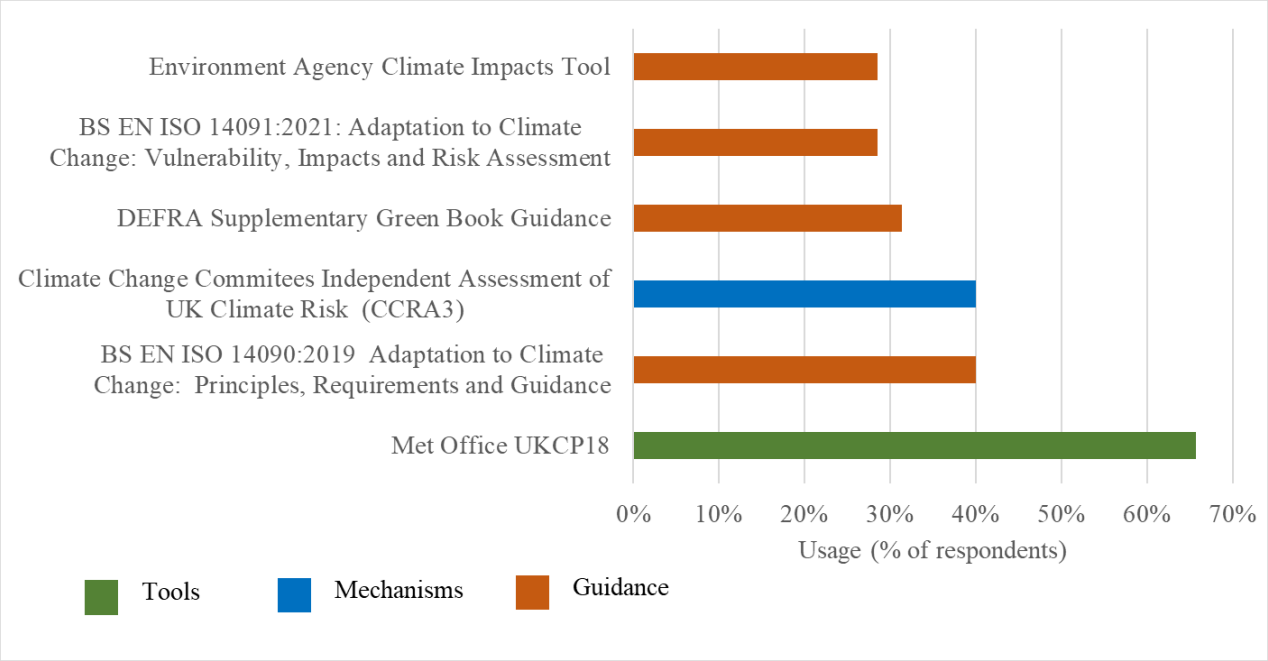

Figure 5. Most widely used tools, mechanisms and guidance based on workshop responses.

The most widely used item, and the only one to be used by over half of respondents, is the Met Office UKCP18 platform. This tool provides access to UK climate projection data and in most cases would be the primary source at the initiation of a climate risk assessment. As noted during the workshop, not all respondents are directly using the platform, but in many cases are having data from UKCP18 interpreted for them by others. Despite the high reported usage of the platform, several workshop attendees reported difficulty accessing and applying climate projection data. This issue included both the usability of the UKCP18 platform, and difficulties understanding how to derive useful hazard information from climate projection data.

"UKCP18 is not in the slightest bit user-friendly".

– Rail sector workshop attendee

The other widely used items are notably high-level. Either providing initial guidance and principles for climate risk assessment, in the case of the ISO standards and DEFRA guidance or giving a first-pass assessment of potential climate impacts across the UK, as with the Environment Agency's tool and the CCRA3.

The rail sector appears to have the greatest uptake of both sector-specific and general tools, mechanisms and guidance. Whereas workshop attendees from other sectors reported using two to four items on average, Rail-sector attendees reported using an average of eleven items. Furthermore, three of the ten most widely used items are internally developed Network Rail tools. This may indicate greater climate risk assessment maturity in the rail sector overall. However, the availability of attendees for the workshop also likely influenced this finding, particularly the absence of National Highways representatives at the workshop.

When asked about their climate scenario requirements for risk assessment, over half of respondents were unsure what emission scenarios their organisation had to consider. Of the respondents that had an idea of their scenario requirements, all but one aimed to at least consider the most extreme emissions scenario, RCP 8.5. Around half of these people also intended to consider intermediate emission scenarios. Respondents from the roads sector tended to have shorter timescale requirements, up to the 2040s or 2060s, compared with Rail, Aviation, and Ports who typically needed to consider up to the 2080s and 2100+.

"I'm at the start of this journey and don't know what is out there or how to choose what meets my needs".

– Ports sector workshop attendee

2.3 Evaluation of Existing Tools

There is no one tool, guidance, or mechanism that will be perfectly suited to every situation, organisation or individual's needs. There is too much complexity and variety to identify 'best' items overall. However, it is possible to recommend items that will be potentially useful for different scenarios, under the understanding better options may be available in some cases. The following are recommended items for users with differing levels of resources and experience in climate risk assessment, they are all applicable to any transport sector.

General - Getting started with Climate Risk Assessment.

ISO 14090:2019 is gaining traction as one of the most widely adopted standard for climate adaptation. It presents a brief outline of what organisations should be considering in climate risk assessment and the wider resilience context. It is best used alongside **ISO 14091:2021**, which expands on the risk assessment process. Given the wide reach of this standard, it can support a consistent methodology across sectors.

The Physical Climate Risk Assessment Methodology (PCRAM) from the Coalition for Climate Resilient Investment provides a useful generalised guide to the core process of climate risk assessment. Although targeted at investors, the methodology would be applicable in other contexts too. The methodology supports the selection of data, definition of performance indicators, assessment of climate impacts on these indicators and subsequent identification and evaluation of resilience options. The UKCIP's **Adaptation wizard** is also a potentially useful resource. It outlines a more detailed procedure, complete with extensive supporting resources, and is UK specific. At the time of writing, the resource hasn't been updated for several years and is outdated in some respects, particularly its reliance on UKCP09 projections and tools. It should only be used as a helpful approach, the data itself should not be relied upon.

Hazard Assessment - Initial Understanding and Communications

For users that are looking to begin a conversation about the potential impacts of climate change on their transport systems, perhaps at the very early stages of risk assessment or in trying to spark interest in a potentially less technical audience, there are platforms to provide quick (albeit limited) visualisation of climate impacts without going into detail.

The UK Climate Resilience Programme's **Climate Risk Indicators platform**, and the National Trust **Climate Hazards platform** both allow users to compare current and future climate indicators. The former provides quantitative changes in key climatic variables (e.g., change in days per year exceeding a given temperature threshold), whereas the latter provides qualitative estimates of climate related hazards (e.g., medium to high storm hazard). The Forestry Commission and Forest Research's climate matching tool provides a unique approach to viewing climate change impacts. The user selects a location and time period and is presented with a map showing locations that currently experience a climate similar to the future projected climate of their selected location, based on a few key variables. Users can examine practices in these regions for potential insights into their own future needs.

Hazard Assessment - Retrieving Climate Projection Data

The Met Office **UKCP18 data platform** remains the primary source for acquiring climate projection data for the UK. As noted, many find the UKCP18 data platform difficult to access. Other platforms hosting climate data, such as the IPCC interactive atlas, may be more user-friendly. However, they do not provide access to UK specific climate data, and subsequently provide lower resolution and fewer options for a UK user. The Met Office provides some guidance on using their projections (Met Office, 2018). However, this does not outline the process of using the data in any

detail. Some attempts at producing a step-by-step guide from other organisations have been identified, but none have yet been found that provide the detail necessary for the transport sector. The Met Office does also provide a training programme with guidance on the use of the UKCP18 data platform.

If transport industry users can become proficient (or be supported) in, using this platform it can provide a host of useful datasets. In addition to providing future climate data, perhaps the most useful resource provided by the UKCP18 platform is their *probabilistic projections of climate extremes* data. It provides annual estimates of the magnitude of extreme weather events (precipitation and high temperatures) at different return periods, indicating the confidence interval, for five different climate scenarios at a 25km resolution across the whole UK. This data can be vital for enabling an initial assessment of how weather risk is likely to evolve over the life of a system.

Vulnerability Assessment – Understanding Impacts Specific to an Organisation

In many cases, vulnerability is likely to be highly specific to the details of the given asset or system being assessed. Sensitivity of an asset to a particular hazard, for example, will likely depend on details of its design, dependencies, context, and condition. Consequently, most approaches to detailed vulnerability assessment will need to be tailored to fit the needs of the assessing organisation. The details of context and condition are usually stored in asset management and inventory tools (see section on Exposure Assessment, below, for further discussion of asset management tools). Some other tools do exist to support the vulnerability assessment process. The **BACLIAT vulnerability assessment process**, included as part of the UKCIP's Adaptation Wizard, is a workshop-based approach to assessing vulnerabilities at an organisational level. A desk-based, speed BACLIAT option is also included. The goal of these processes is to identify vulnerabilities and potential adaptation options, not provide data for a qualitative risk assessment.

Exposure Assessment – Locating Exposed Assets and Systems

As previously noted, the primary requirements for exposure assessment are spatial hazard information and asset location data. The former is covered under hazard assessment, and all the tools, mechanisms, and guidance recommended there can be of some value. Quality asset location data is a product of asset and inventory management tools, which are not within the scope of this review. Typically, transport organisations will produce their own systems for managing asset data, good practice can be found through the Institute of Asset Management.

Criticality Assessment – Considering Implications for Wider Systems

Criticality assessments again are largely dependent on asset data, including data on interconnected systems. Approaches to identifying these connections at a high level mostly consist of stakeholder engagement and cross-organisational collaboration activities. Complex analysis of criticality can be based on catastrophe and scenario modelling. Most identified items for detailed catastrophe and scenario modelling, with inclusion of cascading impacts and criticality of aspects of a network, are commercial or restricted. These include Fraunhofer EMI's CAESAR, the OASIS Loss modelling framework, and the National Infrastructure Systems MODel Risk Analysis Framework (NISMOD). Detailed review of these commercial offerings has not been conducted, and no recommendation can therefore be made.

The **Open Climate Impacts modelling framework (OpenCLIM)**, currently under development and due for completion in August 2023, shows promise in this area. It is an integrated impact assessment model for the whole UK, that looks at the potential impacts of different climate and socio-economic scenarios and planned adaptation on biodiversity, agriculture, infrastructure, and urban areas. Once complete, the model will be hosted on an open-access platform, allowing additional models to be incorporated into the framework, thereby enabling assessment of interactions between systems.

Adaptive Capacity and Cost Benefit Assessment – Determining the Value of Action

Within its high-level climate risk framework, ISO 14090:2019 recommends incorporating adaptive capacity assessment. The standard outlines the areas that should be assessed in an adaptive capacity assessment, and how adaptation planning should aim to improve these areas. It can support users in understanding how to incorporate adaptive capacity into their wider risk management process, although the actual assessment would require other resources.

The final step of the PCRAM details how to make the financial case for investment in resilience and can support cost-benefit assessment. Again, this primarily provides a high-level view of what activities should be undertaken, and how they fit into the wider process.

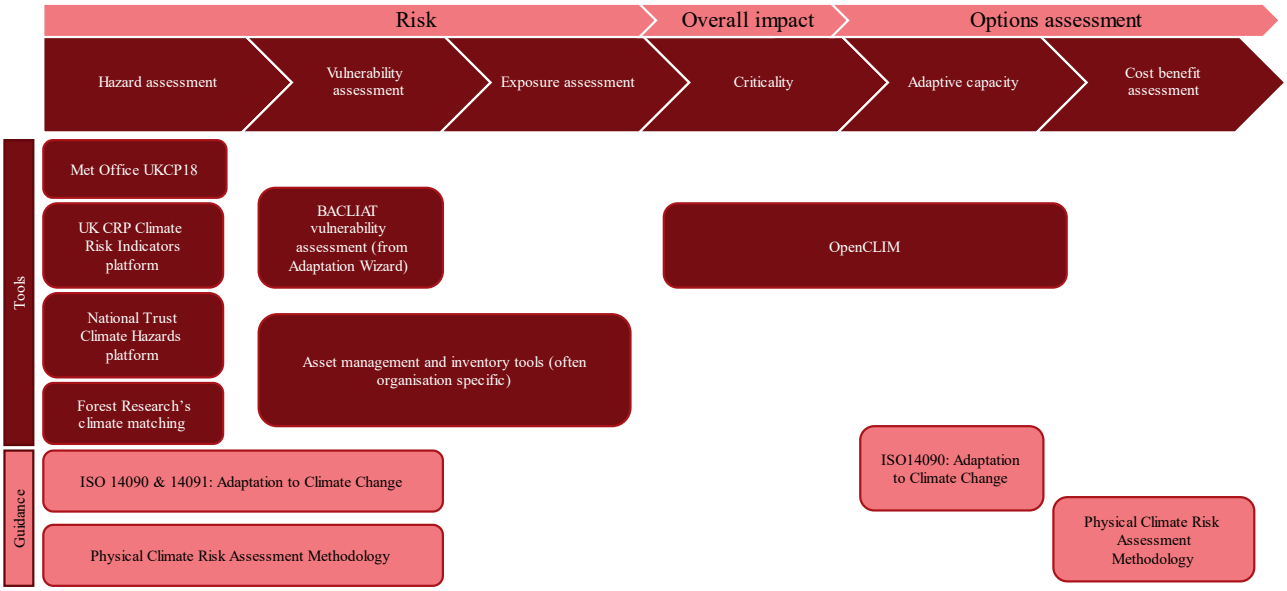

Figure 6. Recommended tools, mechanisms, and guidance mapped against the risk assessment process. Tools are in dark red and guidance in light red, as indicated on the left.

Further information on recommended tools is provided in Appendix C.

2.4 Gaps in the Landscape

Based on our review of the existing tools, mechanisms, and guidance, and on discussion in the workshop, key gaps have been identified both in the available items and the sector overall. These are outlined below.

General

- Gap 1 - Several attendees reported feeling overwhelmed by the existing landscape of tools, mechanisms, and guidance, suggesting a need for increased awareness of available support, and understanding of climate risk assessment across the industry.

> "Many tools and their outputs assume a level of knowledge that most users don't have".
>
> – Rail sector workshop attendee

- Gap 2 - There are few regulatory levers to incentivise organisations that do not report under the adaptation reporting power to conduct detailed climate risk assessments, including the lack of requirements for climate change in design standards. Without this motivation, funding of long-term issues due to climate change can be deprioritised in favour of short-term issues.

- Gap 3 - Generally, few items have been identified that directly quantify climate risk in terms such as incurred costs, disruption times, or harm to individuals. This would require both quantitative hazard projections and vulnerability. Existing vulnerability tools are typically high level, guiding users through a process rather than directly facilitating any calculation. As vulnerability is highly dependent on specific details of an asset, this is unsurprising, and it may not be feasible for general purpose tools to provide this information.
- Gap 4 - Little has been found to support the assessment of transition risks to transport. Roads and Aviation sector attendees flagged this as a particular concern.

> "Very focussed around physical impacts. Significant transition risks to aviation".
>
> – Aviation sector workshop attendee, on limitations of what currently exists.

Hazard Assessment

- Gap 5 - Many organisations appear to be uncertain in their selection of the emissions scenarios and horizons relevant to them. Defra's *Accounting for the Effects of Climate Change: Supplementary Green Book Guidance* provides a simple guide that could aid here (Defra, 2020).
- Gap 6 - There is little to support practitioners in converting climate projection data into hazard frequency and severity data, this was a gap highlighted by multiple attendees from the rail sector. This is an area with a significant body of academic work, but little has been done to translate the research for an industry audience.
- Gap 7 - Tools providing hazard specific information to assess climate risks, such as climate impacts on geotechnical assets, are rare, and often only offer a basic understanding. Tools were found that specifically addressed each of the CCRA3 key risks to transport infrastructure, however in many cases these were very limited in nature. High-level hazard visualisation tools are common, often providing only qualitative results or reflecting a limited set of climate scenarios. Whereas more detailed risk-specific assessments are typically commercial or designed for use by a single organisation.

Vulnerability Assessment

- Gap 8 - There are gaps in understanding of how climatic factors and weather interact with transport assets, beyond flooding, and the impacts of combined risks. Academic research into these factors is extensive, but industry awareness varies greatly between organisations, and even the most advanced still have gaps in their understanding in addition to the gaps within the research itself.

Exposure Assessment and Criticality

- Gap 9 - Interdependencies and cascading impacts are generally not well understood, largely due to a need for coordination with other organisations to achieve this. There is a general need for greater sharing across sectors, both of data and approaches, particularly among sectors with a large range of operating organisations.

Cost-benefit Assessment

- Gap 10 - Few tools exist to directly support cost-benefit assessment, partly due to the lack of quantitative assessment tools. Cost-benefit is primarily only covered at a conceptual level.

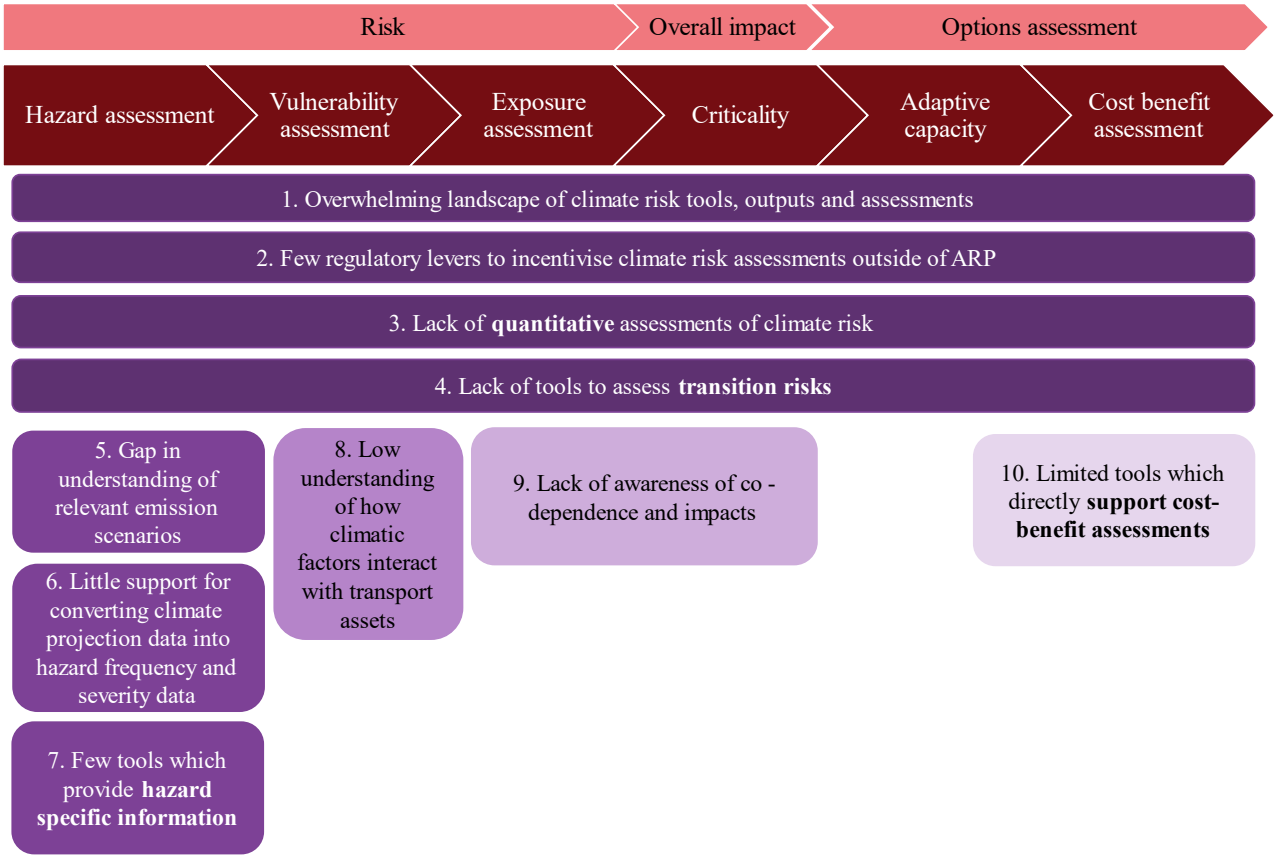

Figure 7. Identified gaps mapped against the risk assessment process.

Hazard assessment is both the area of the risk assessment for which the most items have been identified and that the most gaps remain. There are several reasons for this. At the hazard assessment stage, climate change impacts on a wide range of variables, each of which requires its own unique considerations. Whereas at later stages, the range of climate considerations converges, and issues become increasingly organisationally specific. It is therefore to be expected that there is a greater need for a selection of tools, mechanisms, and guidance at this stage, and that a greater number of gaps remain.

3. Recommendations

Based on the findings of this review, there are several ways that the Department for Transport can continue to help support the UK transport sector in assessing climate risks to their networks and operations. Priority recommendations are indicated in **bold**. Firstly, the Department can use its position to continue help connect transport organisations and share useful resources, helping to fill gaps 1, 5, and 9. This might include:

- **Directing transport organisations to quality existing tools, mechanisms and guidance, and raise awareness of good practice to cut down on confusion in a cluttered landscape.**
- **Recommending an industry-wide, best practice high-level approach to climate risk assessment, either from existing resources or compiling a new one. The high-level process may be similar to that adopted in this report (Figure 2).** This would help reduce duplicated and unnecessary work as each organisation attempts to find a suitable approach, and allow greater consistency across the industry.
- **Continue to facilitate meetings for sharing within sectors to encourage sharing of knowledge and approaches, and develop cross-transport industry interaction.** These should focus on ports, airports, and local authorities' highways departments due to their greater division**.**
- Supporting cross-sector partnerships to deal with interdependencies and cascading impacts, such as the Infrastructure Operators Adaptation Forum (IOAF).

Additionally, the Department for Transport has the opportunity to incentivise transport organisations, in particular local authorities' highways departments that do not report as part of ARP, to carry out climate risk assessments, potentially through risk and cost-benefit reporting requirements, and emphasise the benefits to their long-term operations. This would help fill gap 2. Noting that many individuals are eager to do more in this area, but greater organisational incentives are needed to enable the dedication of resources.

The Department might also consider conducting further reviews into areas of climate risk assessment where understanding could be improved, helping to resolve gap 8 and supporting later recommendations. Work might include:

- A review of research into how weather and assets interact with each other beyond flooding, including the other key CCRA3 risks such as temperature extremes, high winds, erosion, impacts to slope stability and subterranean assets. Work has been undertaken in academia, but not widely adapted for use in transport.

The remaining gaps, where there is a clear need for additional support in the climate risk assessment process, could be filled by Department for Transport developing new tools. The most useful new tools, based on this review, would most likely be:

- **A tool or easy to follow procedure for applying UKCP18 data, particularly to derive hazard frequency data. Noting that the Met Office is reportedly developing a beta tool that could support this area.**
- Sector-wide approaches to calculate the cost benefit of adaptation projects, with a focus on quantifying impacts to networks and assets with and without adaptation, with standardised output specifications.

- Help transition risk to be considered in all risk assessments, through provision of a high-level tool or guide, particularly for airports and local highways (with particular emphasis on the impacts of electric vehicles).

To avoid reproducing work that has been done elsewhere in the world, it is recommended that a review of international good practice, tools, mechanisms, and guidance, across transport and other sectors, is carried out to evaluate how these might be adapted to plug gaps in the UK.

Additionally, it is recommended that infrastructure operators adopt a climate risk assessment process, as outlined in this study, and engage with cross industry forums for their mutual benefit. The gaps and recommendations that respond to them are connected in Figure 8. Priority recommendations, indicated in **bold**, have been identified as those that need to happen first in the roadmap in order to enable successive actions. These recommendations fall into many different types of actions that DfT could take: direction, guidance and funding, introducing regulation, supporting further reviews or directly developing tools. Additionally, we include recommendations where transport operators have a role to play.

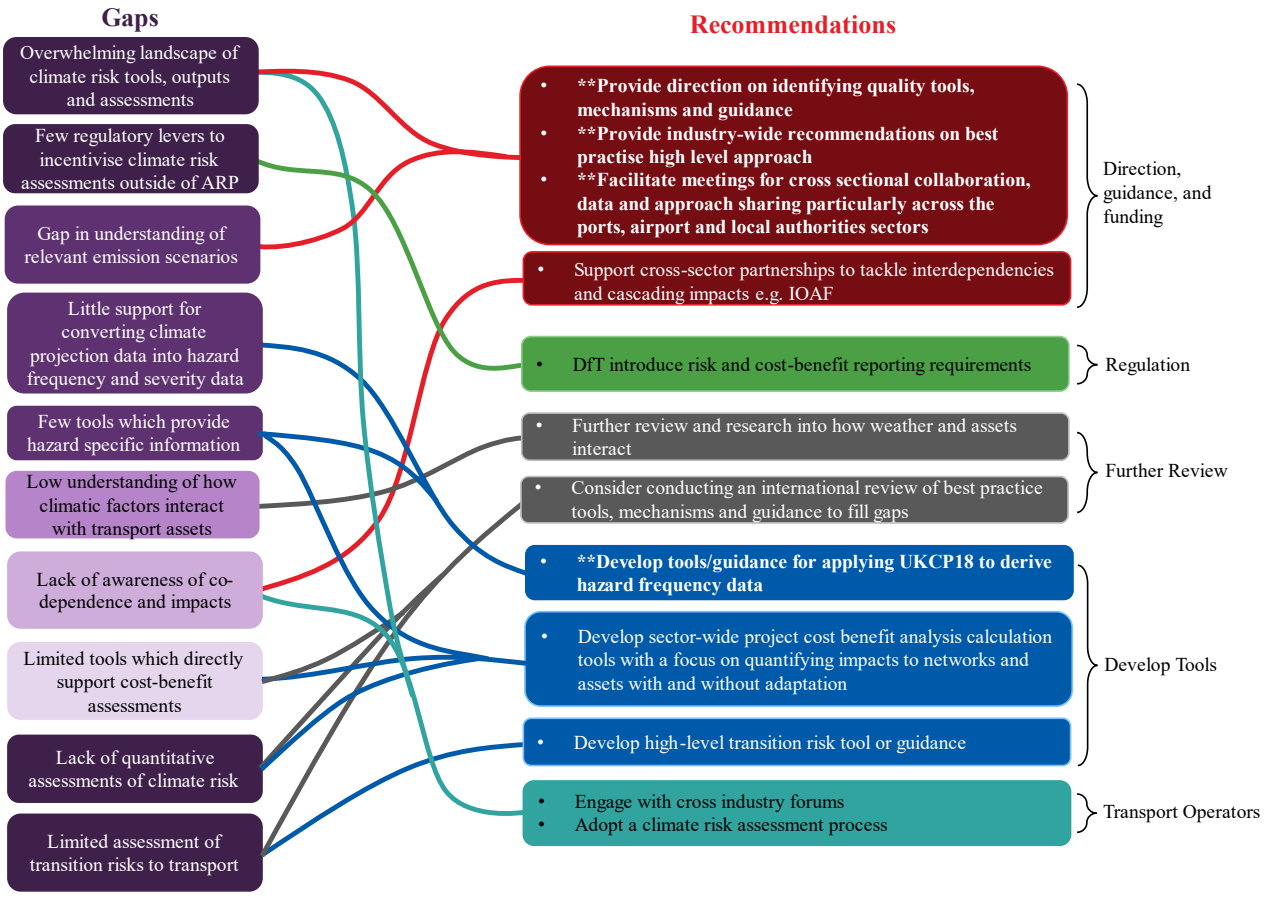

Figure 8.. Recommendations for the Department and Transport Operators mapped against identified gaps they help resolve. Priority recommendations are indicated bold and by **.

Although outside the scope of this study, which was specifically focussed on climate change risk assessment, climate adaptation activities should be aligned with net zero objectives. It is recommended that guidance is provided on aligning climate change risk assessments guidance (this study) with climate change mitigation and carbon management plans, as well as with other national transport sector development plans.

4. References

BSI (2019). Adaptation to climate change – Principles, requirements, and guidelines (ISO 14090:2019).

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IPCC (2023). Climate Change 2023 Synthesis Report. Summary for Policymakers.

Met Office (2018). UKCP18 Guidance: how to use the UKCP18 land projections.

Transport for London (2023). Climate Change Adaptation Plan 2023.

Appendix A: Workshop and Survey Organisations

Attendees to the workshop and survey respondents came from the following organisations.

Sector	Attendees
Highways*	Leicestershire County Council Lincolnshire Country Council Suffolk County Council North Somerset Council Transport Scotland** Transport for London England's Economic Heartland BCP Council Welsh Government
Rail*	HS2 Network Rail Transport for London Transport for Wales TfL (DLR)
Ports	Associated British Ports Port of Milford Haven Dover Harbour Board ABPmer Maritime and Coast Guard Agency
Airports	Gatwick Airport Luton Airport Heathrow Airport

*Includes organisations with cross-sectoral responsibilities.

**Survey respondent only

Appendix B: Taxonomy and Definitions

Tool / Mechanism / Guidance	Description
Tool	An item that can be directly used to facilitate improved climate risk assessment, typically through software or a web application.
Guidance	Steps or recommendations that transport organisations may choose (or be legally required) to follow to better assess and evaluate climate risks.
Mechanism	Other systems, products, or organisational approaches that might facilitate improved climate risk assessment.

Lifecycle Stage	Definition
Policies & Plans	The definition of high-level policies and strategies, and network/region/organisational level planning. Including the identification of risks at a large scale.
Prioritisation	Prioritisation of actions or risk areas in the greatest need of adaptation or mitigative action.
Feasibility & Preparation	Assessment and initial planning of prioritised options for climate adaptation, development into adaptation projects.
Funding & Financing	Securing of private or public funds to facilitate a climate adaptation project.
Design	The conversion of requirement for structures or systems to be included within a climate adaptation project into an implementable design.
Procurement	Procurement of materials, land, services, or any other requirements for the other lifecycle stages.
Construction	Execution of designs in the construction or installation of physical components of an adaptation project.
Operations & Maintenance	The ongoing use, management, and maintenance of a project, likely as part of the wider network.
End of Life	Decommissioning, retrofitting or reuse of project components when they no longer serve their design purpose.

Scale	Description
Network	Intended, or best suited, for use across a given transport network at a national scale.
Region	Intended, or best suited, for use within a local sub-set of a network (e.g. a region, county or city level)
Asset	Intended, or best suited, for use on a single asset
Any	No apparent intention, or suitability, for use at a specific scale over any other.

Output Type	Description
Decision-making	Actionable outputs for decision-making, e.g. a prioritised list of interventions to be made
Supporting Data	Data to enable more risk informed decision-making, e.g. risk mapping, that isn't immediately actionable

CCRA 3 Key Risk to Transport Infrastructure	Description
I1.	Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures
I2.	Risks to infrastructure services from river, surface water and groundwater flooding
I3.	Risks to infrastructure services from coastal flooding and erosion
I4.	Risks to bridges and pipelines from flooding and erosion
I5.	Risks to transport networks from slope and embankment failure
I7.	Risks to subterranean and surface infrastructure from subsidence
I12.	Risks to transport from high and low temperatures, high winds, lightning
Generic (Non-CCRA3 Risk)	Generic. Item that does not explicitly focus on specific risks, or that could be applied to any climate risks (e.g. climate projection data).
Transition (Non-CCRA3 Risk)	Transition. Risks deriving from transitioning to a lower carbon economy/society to mitigate climate change, rather than physical impacts of climate change itself (e.g. transition to electric vehicles)

Usage Tag	Description
In Use	Identified case(s) of this tool/mechanism/guidance being applied by a transport organisation within the UK
None Identified	No identified cases of this tool/mechanism/guidance being applied by a transport organisation within the UK

Discrete/Ongoing Use	Description
Discrete	Tool/mechanism/guidance is intended for usage for a project/organisation at a given point in time, without any consideration of ongoing applicability, monitoring, evaluation, or adaptation pathways.
Ongoing	Tool/mechanism/guidance considers ongoing applicability, monitoring, evaluation, or adaptation pathways.

Assessment Type	Description
Hazard	The potential occurrence of a physical event (often in terms of frequency and magnitude) or trend that may have an adverse effect on transport systems, infrastructure, users, or workers. Includes tools which allow the assessment of hazard present at an asset/network location, which could be considered a separate assessment (exposure) in some guidance, but for the purposes of this review disaggregation is not required.
Exposure (spatial hazard)	Predisposition of the asset, network or system to be adversely affected based on its location. As asset management and inventory tools are not within the scope of this review, this focuses on items that enable hazard assessment based on location.
Vulnerability	The propensity or predisposition of a given transport system/asset/user/worker to be adversely affected by a climate hazard. Includes sensitivity of assets, materials, individuals etc. to the hazard in terms of damage, safety, and disruption. For this review also includes 'exposure' assessments that do not consider details of the climate hazard itself, only the generalised asset location. For example, an asset that is exposed to coastal flooding based on proximity to coastline.

Assessment Type	Description
Criticality / Consequence	Groups assessments that consider the possible outcome of an adverse event, i.e. the extent to which damage or disruption to a transport system or sub-system would impact on wider aspects of the same system, interdependent infrastructure, or society at large. This includes direct and indirect costs. Criticality assessments often assess the extent to which other assets or systems are dependent on the assessed element and the potential for cascading failures.
Adaptive capacity	The ability to adjust to climate change risks (such as climate variability and extremes). This will be constrained by factors such as the information available, and the incentives individuals and organisations face. Tools, mechanisms and guidance which only assess adaptive capacity are considered out of scope for this project.
Cost-Benefit	Quantification of direct and indirect costs and benefits associated with an option to mitigate climate risk as part of option evaluation and/or prioritisation.

Output Complexity Tiers	Description (Modified from Linkov et al.)
Tier 0	No hazard/risk assessment, supporting information only e.g. climate projection data
Tier 1	High level risk/hazard assessment. E.g. identifying key climate impacts, qualitative or semi-quantitative hazard assessment, or high level parameter adjustment
Tier 2	Detailed assessment involving vulnerability/criticality assessment, cost-benefit assessment, prioritised decision-making etc.
Tier 3	Complex modelling of interactions between climate risks and vulnerable elements, robust scenario analysis

Delivery Level	Description	Use case statement
Level 1 – High user responsibility	Approach - The item provides high-level steps or recommendations in an approach to achieve the output, but significant additional reasoning is required on the user's behalf to apply the approach fully	"These recommendations could allow you come up with a way to achieve [output]"
Level 2	Process - The item provides a detailed process to reach the give output. The user needs only to apply this process to their system with minimal adjustment.	"Follow these steps and you will achieve [output]"
Level 3	Application - The item delivers the climate risk assessment, the user only provides inputs or adjusts the application as needed, e.g. most simulation software.	"You can use this to generate [output]"
Level 4 – Low user responsibility	Output - The item provides the output directly	"Here is [output]"

Appendix C: Recommended Tools, Mechanisms and Guidance

Name	Organisation	Primary Recommended Use(s)	Description	Available At
The Physical Climate Risk Assessment Methodology (PCRAM) - Guidelines for Integrating Physical Climate Risks in Infrastructure Investment Appraisal	Coalition for Climate Resilient Investment	Getting started with climate risk assessment (high-level)	Developed by the Coalition for Climate Resilient infrastructure as a guide targeted at investors. PCRAM enables a rigorous interpretation of climate risk analytics and related science to assess the operational, commercial and financial materiality of an infrastructure asset, beyond a traditional approach exclusively focused on i. loss & damage assessments, ii. acute hazard only, and iii. immediate to short-term horizons. The process follows 4 key steps: scoping and data gathering, assessment of asset resilience, identification of resilience options, and de-risking with cost-benefit assessment.	https://resilientinvestment.org/pcram/
BS EN ISO 14090:2019 Adaptation to Climate Change - Principles Requirements and Guidelines & BS EN ISO 15091:2021 Adaptation to Climate Change – Guidelines on vulnerability, impacts and risk assessment	BSI	Getting started with climate risk assessment (high-level)	The British Standards Institute's UK implementation of the international standard, this aims to give to give a high level overview of climate adaptation. The 14090 standard specifies the principles, requirements, and guidelines for adaptation to climate change, and details how this adaptation can be integrated within and across organisations. This includes brief discussion of climate hazards, risk assessment, vulnerability assessment and adaptive capacity assessment., followed by discussion of options identification, monitoring, and evaluation. Whereas 14091 expands on guidelines for assessing the risks related to the potential impacts of climate change. It describes how to understand vulnerability and how to develop and implement a sound risk assessment in the context of climate change. It can be used for assessing both present and future climate change risks. Risk assessment according to this document provides a basis for climate change	https://www.iso.org/standard/68507.html

Name	Organisation	Primary Recommended Use(s)	Description	Available At
			adaptation planning, implementation, and monitoring and evaluation for any organization, regardless of size, type and nature.	
Adaptation Wizard	UKCIP	Getting started with climate risk assessment (high-level) Vulnerability assessment	Created by the UK Climate Impacts Programme at the University of Oxford, with the primary goal of supporting the development of climate change adaptation strategies. The Adaptation Wizard provides guidance on assessing current climate vulnerability, future climate vulnerability, adaptation options, and monitoring and renewal. The guidance is provided in the form of a high-level process supported by a number of additional resources and tools, templates and checklists. **Note that parts of the process rely of UKCP09 data and are therefore outdated.** The overall approach however is still valid.	https://www.ukcip.org.uk/wizard/
Climate Risk Indicators Platform	UKCRI	Initial understanding and communication of climate risk	Created by the UK Climate Resilience Programme and collaborators, this platform synthesises climate UKCP18 projections for rapid analysis. Allows the user to view projections over time of climate risk indicators (such as temperature change, heat waves etc.) based on various scenarios across the UK at a county scale. Includes road and rail specific indicators of road melt risk, road accident risk (due to low temperatures), high rail temperatures, and adverse rail weather days.	https://uk-cri.org/

Name	Organisation	Primary Recommended Use(s)	Description	Available At
National Trust Historic Environment Scotland Hazard Map	National Trust	Initial understanding and communication of climate risk	The National trust provides this interactive map of the UK which shows a qualitative estimate of a selection of climate hazards. Including current and future overheating and humidity, storm damage, slope failure, and soil heave hazard. The tool overlays National Trust heritage sites, and is originally intended to enable assessment of the risks presented to these site. However, it serves as a useful first pass for any sector.	https://historicengland.org.uk/whats-new/research/back-issues/mapping-climate-hazards-to-historic-sites/
Open Data Platform - Climate Matching Tool	Forest Research	Initial understanding and communication of climate risk	Forest Research offers a range of resources to examine the impacts of climate change on forestry in the UK. The resource with the greatest potential value to transport is the climate matching tool. This allows the user to select a location in the UK and a future date range, the tool then identifies areas of Europe or the Pacific Northwest of America that currently have a climate that most closely matches the projected future climate at the chosen location. The climate parameters considered are precipitation, temperature and diurnal range. This is a simple to use tool that can help users to consider how their practices might need to change through comparison with existing practice elsewhere in the world. It is also a useful way to convey complex climate change in an easily understandable form.	https://www.forestresearch.gov.uk/tools-and-resources/fthr/climate-matching-tool/
UKCP18 - Climate Projection Data	Met Office	Accessing climate data	The Met Office has created this platform providing a diverse catalogue of UK-specific climate projection data. It is the primary source of climate projection data for any sector in the UK and is likely to be a necessary component of any detailed climate risk assessment. The same site additionally provides some very high-level guidance on usage and understanding of the data.	https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/data/index

Name	Organisation	Primary Recommended Use(s)	Description	Available At
OpenCLIM	Tyndall Centre for Climate Change Research	Assessment of complex interactions and criticality	Currently under development by the Tyndall Centre for Climate Change Research at the University of East Anglia, this tool provides a UK wide view of interacting climate impacts and risks. The model framework developed by the project links existing models to consider UK-wide climate impacts and risks, including potential adaptation options. In this first version, it considers the implications of climate change on agriculture, heat stress, inland flooding, and drought/water supply, including expansion of infrastructure and urban areas, biodiversity and land cover dimensions. All these factors are combined to produce an overall estimate of risk. The model is hosted on an open platform, to enable ongoing development and continuous updating.	https://tyndall.ac.uk/projects/openclim/