



The Costs of Adaptation for UK Transport and Land Systems



Supporting Research to the Climate Change Committee. March 2026

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Summary

This supporting research has been undertaken for the Climate Change Committee by Paul Watkiss Associates. The work has been funded by the ACCREU project (Assessing Climate Change Risk in Europe) and the ATTENUATE project (Creating the enabling conditions for UK climate adaptation investment).

The research undertakes an initial assessment of the costs of adaptation for the transport and land systems through to 2050 for the UK. The approach follows established methods for adaptation cost allocation and categorises adaptation into:

- i) Targeted adaptation investments where the primary objective is adaptation and all the cost is counted, e.g., coastal protection to sea-level rise;
- ii) Climate proofing, where adaptation is not a primary objective and only the incremental adaptation cost is counted, e.g., the additional cost to make new roads more resilient; and
- iii) Mixed cases, where there are multiple objectives and some costs are attributed to adaptation.

The approach starts with published costs where these are available, and then uses various analytical approaches to derive future estimates. It is stressed that future adaptation costs will be dependent on the objectives set, and whether these are based on the economic optimal level, acceptable levels of risk or current risk levels. Due to the nature of this rapid analysis, it has not been possible to consider different objectives and the estimates here can only be considered indicative. Further work to develop adaptation costs and benefits for these systems, and investigation of the trade-offs of different objectives, is recommended.

Transport system

There are a multiple climate change risks to transport. The main focus of adaptation costs in this analysis has been on the costs of increasing the climate resilience of new transport infrastructure and renewal programmes (climate proofing), as well as targeted retrofitting of vulnerable existing assets. The findings are summarised below.

- There is surprisingly little published information on current adaptation spend in the transport sector.
- Data do exist for the railways from the regulatory process and infrastructure operator submissions. These indicate proposed spending of £520 million/year for Great Britain over the five year period of 2024 to 2029 for weather resilience activities and climate change adaptation.
- Network Rail is working to develop estimates of future adaptation and resilience costs for the next two periods FP1 (2029–2034) and FP2 (2034 to 2039), but the levels will be determined through the funding review process.
- There are also costs associated with the climate proofing of High Speed Rail 2, from the integration of higher climate resilient design standards, though data on the incremental costs are not available.
- There are no equivalent data on adaptation and resilience spend for roads. While there is some information on adaptation actions for the strategic road network, there is no information for local roads. There are not good data on the adaptation costs associated with urban transport, and no adaptation cost data for airports or ports.
- Future adaptation costs will be strongly determined by the objectives set, noting for transport infrastructure there are issues of safety. Aiming to keep residual damages similar to today, or maintaining current service or safety levels, will involve higher costs.

- Given the lack of published information it is difficult to assess future adaptation costs with confidence. To provide indicative estimates, the analysis here has used climate adaptation mark-ups, combining these with future transport investment profiles.
- This indicates a central range estimate of approximately **£0.95 billion to £2.57 billion/year for the 2030s** for Great Britain for road and rail networks. It is stressed that these estimates do not include the costs of adaptation for ports, airports, or waterways.
- These costs are likely to rise in the 2040s and 2050s, due to the very large number of transport assets across transport networks, especially for high warming scenarios.
- More information on adaptation costs will emerge with upcoming rail and road investment strategies later this year, but further evidence is needed to gather robust cost estimates for future periods and for the overall transport system.
- There is some information on the economic benefits of this additional adaptation, from the international literature and from specific UK case studies. This indicates net positive economic returns, however, these vary strongly with site and context, and in practice, adaptation involves complex decisions and requires pathway thinking to address future climate uncertainty.

Indicative Adaptation Costs for Road and Rail for Great Britain (£/year)

Theme area	Current	2030s	2040s	2050s
Rail operator submissions*	£520 million/year			
Strategic and local road networks	No data available			
Total road and rail central estimate (new and renewal)**		£945 million - £2,570 million/year	Not quantified	Not quantified
Total road and rail high estimate	Not quantified but could involve much higher costs, due to retrofit challenge for adaptation of existing assets, especially high warming			

See main report for notes.

*Source Network Rail.

**Source authors. Based on adaptation mark-ups and NIC projections. The range reflects range from the literature. Note that NIC projections are used as analytical baseline for the modelling in this report, but are not produced by Network Rail or National Highways.

Land system

The land system includes risks to biodiversity and habitats (terrestrial and coastal), farmland including soils, woodlands, uplands and freshwater. Climate change will have multiple risks to this system, involving natural capital and ecosystem services, but these have to be seen in the context of other non-climate drivers and pressures. This makes the analysis of adaptation challenging, including the attribution of adaptation costs to actions that have multiple objectives. The potential adaptation costs for the land system have been assessed, though these again can only be considered indicative. The findings are summarised below.

- There is data on public spending for many components of the land system, for example biodiversity spend and agricultural payments, but it is not possible to easily split out the proportion of these which can be counted as adaptation.
- There were many actions in NAP3 in the natural environment theme (which corresponds closely to the land system). These included actions from the 25 Year Environment Plan (25YEP) and Environmental Improvement Plan (EIP), but most were not costed.
- NAP3 cited the biodiversity targets (30 by 30 targets) for England as a key adaptation action. The costs of meeting these biodiversity targets were assessed in a Government impact assessment (IA), which included an analysis of adaptation costs (the costs of

climate proofing the biodiversity targets). This analysis also looked at future adaptation costs, from 2030 to 2042, and these values have been used here. There are not good equivalent data for the other Das, and to provide indicative UK costs, the values from England have been scaled to the UK based on area targets for the 30 by 30 goal.

- These biodiversity adaptation costs will rise, potentially significantly, in the 2040s and 2050s, especially under higher warming. This will require more active adaptation actions and adaptive management, though benefits are likely to outweigh costs.
- The NAP3 also included peatland restoration, but this is undertaken for multiple reasons. There is not good data on climate risks and adaptation benefits (on-site and off-site). An initial analysis has been made based on post 2030 peatland restoration rates (aligned to the CCC 7th Carbon Budget), with a 25% attribution % of restoration costs to adaptation.
- Similar issues arise for woodlands. An indicative analysis has been made based on post 2030 woodland creation rates (CCC 7th Carbon Budget), but with a lower (5%) attribution. However, an additional adaptation cost is included to ensure new woodlands are climate resilient. The costs of adapting the large stock of existing woodland will potentially be much higher, but there is insufficient information to allow estimation .
- Adaptation costs to address wildfires are included, primarily focusing on peatlands and woodlands, with early warning, awareness raising, and Wildfire Management Plans including associated low regret actions. More extensive actions are difficult to justify because of the low risk and high costs, but might likely be needed post 2040.
- The potential adaptation costs for farmland has assessed.
 - Agri-environmental schemes that are habitat creating or supporting. These are covered in biodiversity costs above.
 - Adaptation public goods (e.g., natural flood management), with provisional estimates based on a highly targeted approach to high risk areas in England only. These will be superseded later this year by LTIS2.
 - Actions that have multiple environmental objectives and deliver positive externalities, particularly soil management. Some very indicative estimates for the attributed adaptation costs of soil management actions have been made.
 - Adaptation to address the productivity losses from climate change. This includes:
 - Public actions to support barriers to adaptation, based on a higher level of adaptation spend in extension and information programmes post 2030.
 - Water management including irrigation, but note these adaptation costs are included in the CCC water system, and not duplicated here.
 - Additional private adaptation costs (additional to soil and water management), though it has not been possible to assess these.
- It has not been possible to provide an estimate of the costs of adaptation for freshwater, or for pests, disease and invasive species, but both of these are major omissions.
- Given the lack of published information and studies, it is difficult assess future adaptation costs with confidence for the land system. The numbers from this rapid study indicate a central estimate of approximately **£0.8 billion to £1.2 billion/year for the 2030s**, but this omits a large number of important areas, and is therefore a sub-total of all adaptation costs. These costs are likely to rise in the 2040s and 2050s, potentially very significantly under high warming scenarios.
- It is also noted that for a number of these interventions –the 30 by 30 targets, peatland restoration, woodland creation and soil management – the cost below only relates to the adaptation attributed fraction: the total costs of delivering these actions will be much higher, but they also deliver multiple benefits.
- Further evidence is needed to gather robust cost estimates for future periods and for the overall land system.

- There is some information on the economic benefits of many of the adaptation interventions for land, and these indicate net positive economic returns, though this is due to the multiple benefits involved (not just risk reduction). These returns vary strongly with site and context, and in practice, adaptive management approaches will be needed to address future climate uncertainty and other challenges.

Indicative Adaptation Costs for the Land System for the UK (£/year)

Theme area	Current	2030s	2040s	2050s
Biodiversity	Not available	£440 million to £730 million/year	Not quantified	Not quantified
Peatlands and Woodlands, including wildfire management		£120 million/year	Not quantified	Not quantified
Farming including soils		£190 million to £310 million/year	Not quantified	Not quantified
Freshwater		Not quantified	Not quantified	Not quantified
Sub total		£750 million to £1160 million/year	Not quantified	Not quantified
Total	Not quantified			

See main report for notes. Source authors..

Introduction

This supporting research has been undertaken for the Climate Change Committee by Paul Watkiss Associates. The work has been funded under the **ACCREU project** (Assessing Climate Change Risk in Europe)¹ and the **ATTENUATE project** (Creating the enabling conditions for UK climate adaptation investment). The supporting research is investigating the potential costs of adaptation for the transport and land systems, to feed into the CCC's well-adapted report which will be published alongside the 4th Climate Change Risk Assessment (CCRA4) technical analysis.

Approach and Methods

Adaptation economics and setting objectives

This analysis aims to assess the potential costs of adaptation for the transport and land systems, from today to the 2050s. These costs will be strongly influenced by the objectives that are set for adaptation, and the associated level of ambition.

In the UK, policy objectives are usually developed through the concept of welfare economics (HMT, 2022). This is concerned with social or public value and not simply market efficiency. This considers all the relevant costs and benefits that affect wellbeing, including environmental, cultural, health, social and justice effects, and not just market costs and benefits. This framework can be applied to adaptation as in Figure 1 below. This shows rising economic costs of climate change (on the left, in red). Adaptation reduces these impacts, producing an economic benefit. This can be compared to the costs of delivering these benefits, i.e., the costs of planning, preparing for, facilitating and implementing adaptation measures. However, adaptation is rarely completely effective, and there is nearly always a residual economic costs after adaptation (on the right, in green). This leads to a trade-off between adaptation costs and benefits, and residual damage, because adaptation usually becomes less cost-effective (and disproportionately more expensive) with progressively higher levels of risk reduction.

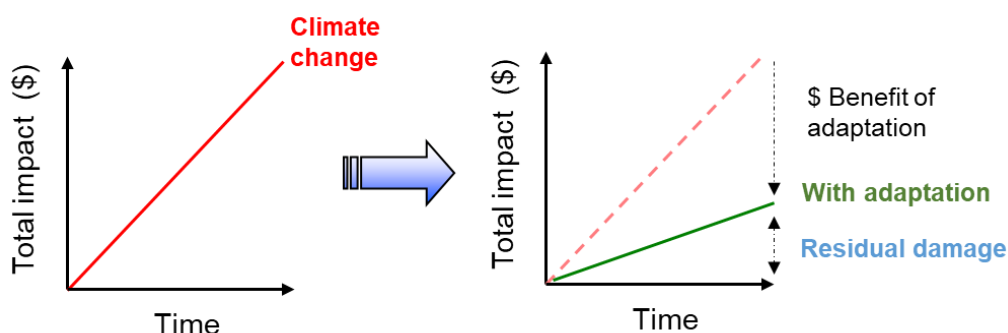


Figure 1 Schematic of the Trade-off between Adaptation Costs, Benefits and Residual Damage. Updated from Boyd and Hunt, 2004.

¹ This work was supported by the Assessing Climate Change Risk in Europe project (ACCREU), funded by the European Union through the Horizon Europe Research and Innovation Action (RIA) under grant agreement 101081358 and by UK Research and Innovation (UKRI) under the United Kingdom Government's Horizon Europe Guarantee (reference number: 10073932). Note that the views and opinions expressed are, however, those of the author[s] only, and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them. It was also supported by the ATTENUATE project (Creating the enabling conditions for UK climate adaptation investment) project, supported by UK Research & Innovation grant number UKRI282

In theory, it might be possible to derive the economic optimal level of adaptation, where marginal benefits equal marginal costs. However, this optimal level might lead to high levels of residual damage, especially as adaptation is not perfectly effective (for example, see the review of Rexer and Sharma, 2024). For these reasons, objectives to current climate related risks are often set based on other criteria, such as an acceptable levels of risk.

All of this means that setting adaptation objectives involves complex political and ethical considerations (UNEP 2023a), not just economic efficiency. The preferred objectives and level of adaptation/residual damage will therefore vary with different actors, as well as wider societal risk preferences and the willingness to pay for adaptation costs / accept residual impacts. Importantly, the approach to target setting for different climate related risks can be set using different framing perspective, and it is not consistent across the economy today e.g., the approach to climate and health is different to flood protection, see Watkiss et al., 2019.

In practice, even once the approach to setting objectives is made, estimating the actual costs and benefits of adaptation is extremely challenging for multiple reasons. Climate change involves location and context-specific risks, involving slow-onset change and extreme weather events, which are determined by local hazard, exposure and vulnerability (Field et al, 2014). These climate risks change over time, and involve deep uncertainty, from the combination of different emission and socio-economic scenarios, variations in the climate model projections, differences between impact models, and adaptation effectiveness (Wilby and Desai, 2010).

Mirroring these challenges, adaptation requires site and context specific responses, involving both reactive and anticipatory decisions (Burton, 2009), and decision making under uncertainty (Watkiss et al., 2014) taking account of time preferences around future costs and benefits. It usually requires a mix of different types of responses, which include capacity building, institutional strengthening and awareness raising (soft options) as well as technical, structural, or engineered actions (hard options) (Portner et al, 2022). These are normally combined in portfolios of actions, which change iteratively over time as part of continuous cycle of learning, as iterative pathways of climate resilient development (Porter et al, 2022). Adaptation is therefore often seen as a process, rather than a set of single set of technical solutions.

Adaptation definitions and attribution

A further issue when developing cost estimates is on what counts as adaptation, and boundaries, baselines and definitions. Adaptation costs are higher if adaptation deficits are included (i.e., actions that tackle existing natural climate variability and extremes, UNEP, 2016). They are lower if only adaptation to the incremental impacts of climate change are included, but even these vary with the baseline considered (i.e., whether these are incremental costs relative to the 1990s or today).

Similarly, there are different definitions of what counts as adaptation, including whether to count general activities that increase household incomes and so build resilience, or whether intent to specifically address climate risks is required. There are also related issues of attribution, especially where an intervention has multiple objectives (and benefits), only one of which is adaptation.

To partly address these issues, an adaptation taxonomy is used that assesses different types of adaptation and attributes costs. This is based on the adaptation tracking approach developed by the MDBs (MDB, 2022) and includes three main categories.

- **Building climate adaptation into proposed programmes and investments** (climate proofing). In this case, adaptation is not a major objective, and the analysis is interested in the incremental costs of adaptation, over and above the core programme / investment costs. An example would be the costs of making new roads more resilient, and the incremental costs of higher design standards that take account of climate change. Note that in this case, the benefits of adaptation only arise from the incremental benefits of adaptation, i.e., the benefit of reducing climate risk to the road, and not the benefits of the road itself.
- **Targeted adaptation programmes and investments** (pure adaptation). In this case, the primary objective of the policy, programme or project is adaptation to climate change. An example would be investing in coastal flood protection to address sea-level rise. In this case, the total costs of the investment is counted as adaptation. This also translates across to the benefits, as adaptation is the main driver of economic benefits.
- **Investments with multiple benefits that include adaptation** (mixed objectives). Sitting between the two cases above are a set of investment where adaptation is one of a number of objectives (a secondary or significant objective). An example would be investing in peatland restoration. This will lead to greater resilience of the peatland (to climate change) as well as off-site benefits (water management) but this investment is primarily associated with carbon storage, biodiversity and ecosystem services. In this case a proportion of the cost could be attributed to adaptation, but this is often difficult to do accurately and involves subjective decisions.

These three cases are illustrated in Figure 2 below.

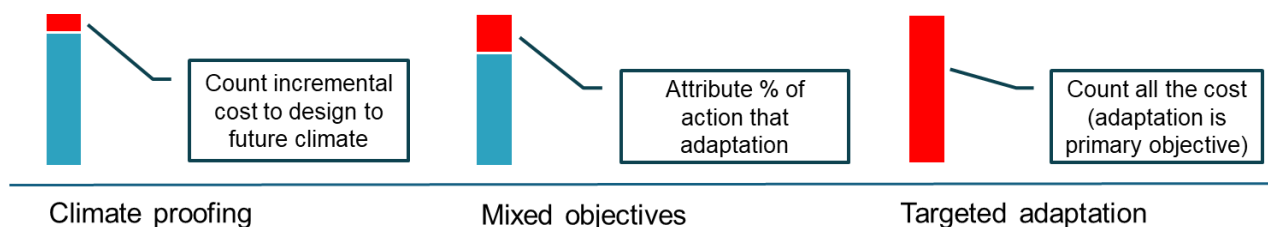


Figure 2 Schematic of the three types of adaptation investment in this study.

Transport System

This supporting rapid research aims to investigate the potential costs for the UK transport system. This covers roads (the strategic road network and local roads), rail, urban transport (above and underground), waterways and marine (including ports) and air travel (especially airports).

Climate risks and future damages to the transport system

There are a multiple climate change risks to the transport system which include (ADB, 2021):

- Loss or damage of transport infrastructure assets;
- Increases in operation and maintenance costs;
- Reduced economic benefits or revenues (e.g., transport disruption and travel time delays, lost revenues, cashflow variability, cascading risks and wider economic impacts).
- Increases in the economic impacts associated with the use of transport infrastructure, e.g., increased accidents, fatalities and injuries.

While the main focus of adaptation has been on avoided losses, and especially on reducing risk to transport infrastructure, there is some potential for positive benefits, from options that enhance performance (for individual assets and at the network level) or that provide cost savings, increased revenue or economic benefits.

In the UK context, the risks of climate change to transport were assessed in the CCRA3 (Jaroszweski et al., 2021) as part of the broader risks to infrastructure. CCRA3 also assessed the potential level of economic costs of these risks (Watkiss et al., (2021), shown in Table 1 below.

Table 1 Economic Valuation of Risks and Opportunities for Transport Infrastructure. Source: Watkiss et al., 2021.

Risk / Opportunity	Present Day	2050s	2080s, 2°C	2080s, 4°C	Confidence
I1. Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures	H	VH	VH	VH	Low
I2. Risks to infrastructure services from river, surface water and groundwater flooding	H	H – VH	H - VH	VH	Low
I3. Risks to infrastructure services from coastal flooding and erosion	M	M	M	M	Low
I4. Risks to bridges and pipelines from flooding and erosion	M	M	M	M	Low
I5. Risks to transport networks from slope and embankment failure	M	M – H	M - H	H	Low
I7. Risks to subterranean and surface infrastructure from subsidence	M	M	M	M	Low
I12. Risks to transport from high and low temperatures, high winds, lightning	M - H	M – H	M - H	M - H	Low

Key

Risks	Opportunities	
VH	+VH	£billions/year
H	+H	£hundreds of millions/year
M	+M	£tens of millions/year
L	+L	£<10 million/year

The magnitude of risks has been updated in CCRA4 (Ferranti et al., to be published 2026), though these are still provisional. These do indicate higher risks, even today. They are also higher through to the 2080s, though confidence decreases.

Table 2 Provisional scoring of Transport Risks in CCRA4 (Ferranti et al. forthcoming).

Risk	Present	2030	2050	2080	Urgency
11. Risks to the delivery of infrastructure services from interdependencies	H	H	VH	VH	CAN
15. Risks to road transport systems	H	H	H	VH	CI
16. Risk to rail transport systems	H	H	H	VH	MAN
17. Risks to aviation, shipping, and other transport systems	H	H	H	H	CI

CAN = Critical Action Needed, CI= Critical Investigation. MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action

It is stressed that these future impacts are influenced by future socio-economic change as well future climate change. This will include the effects of decarbonisation, which will influence the relative share of transport and climate risks. This socio-economic change will also include the increased population and larger economy of the future, which will drive more investment in transport infrastructure, and increase the value at risk. It is noted that future economic growth is only factored into the CCRA4-IA commissioned research projects and is not included in many of the well-adapted sectors (in quantitative terms).² For this reason, the costs presented here should be seen as the adaptation costs associated with the current economy (and they would need to be adjusted to compare to cost of inaction numbers for the future that do include economic growth).

Assessing adaptation costs and benefits for transport

Transport infrastructure has a long lifetime and new investments built over the next decade will operate under very different climate conditions to today. This means that choices on the design of individual assets, but more broadly transport networks, can lock-in patterns of risk for decades. Further, in many cases, once transport infrastructure and/or land-use change associated with transport have occurred, they are often difficult or costly to reverse (irreversible or quasi-irreversible). This has led to a focus on the need to increase the climate resilience (climate proof) ³new infrastructure, as well as enhance climate resilience in refurbishment and renewal programmes.

However, there are complex economic considerations associated with this adaptation, because of the need to consider time preference (discounting). Climate proofing involves upfront adaptation costs. This can provide some early benefits from current and early climate change, but a large proportion of benefits will arise in the future, and which will therefore be low in present value terms (though this will depend on the lifetime of the infrastructure and the level of climate uplift and resilience factored into the design). Furthermore, future climate change risks, and thus future benefits, are subject to high levels of uncertainty.

From an economic perspective, this means adaptation infrastructure decisions are more nuanced than many assume, and there is a high risk of economic maladaptation. For example (ADB 2015) finds it makes economic sense to climate proof new infrastructure if the costs of climate proofing are low and the benefits (the avoided costs) are large, even though

² For example, such effects are normally included in transport economic appraisal, asset out in UK government guidance in the Transport Analysis Guidance (TAG) (DfT, 2025). These provide the framework for assessing the costs and benefits for the transport sector. These include the guidance for cost-benefit analysis and the methods for assessing various economy, environmental and social benefit streams, as well as wider economic effects. They also provide guidance for how these costs and benefits should be adjusted in future years, in line with economic growth. As examples, travel time benefits or valuation of accidents are increased over time in line with the change in real GDP per capita. This changes the future economic impacts of climate change, and thus changes the adaptation economic return.

³ The term climate proofing is often used, though it is often not possible, and/or not economically efficient, to complete climate-proof infrastructure against all risks.

they occur in the future. It also makes economic sense if the costs of climate proofing in the future are expected to be prohibitive or retrofitting later is technically not possible. However, the converse of this is if there are not large future risks, and/or retrofit is easy and low cost, then it will be more economically optimal to adapt later.

This important because transport infrastructure components have different long life-times, and not all of them involve irreversibility. An example is shown below (Highways Agency, 2011). It makes more sense to climate proof long lived investment with elements of irreversibility, e.g., bridges (see right), but not short-lived investments (see left), e.g., road surfaces are updated frequency, so there is no need to climate proof them for the 2080s.

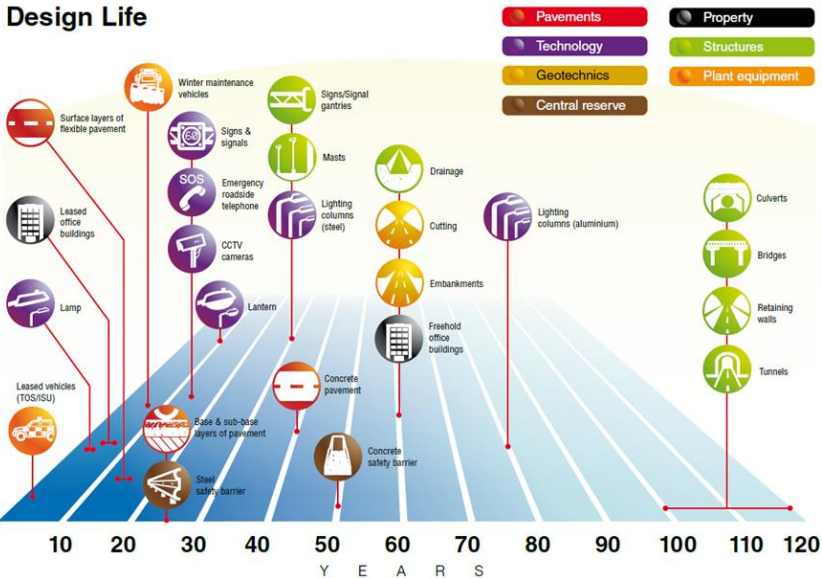


Figure 3 Example of design life for road infrastructure components. Source Highways Agency.

This has led to a focus on decision making under uncertainty in the literature, especially for individual assets. These include techniques such as robust decision making, real options analysis or dynamic adaptation pathways (see Watkiss et al., 2014; Bonjean Stanton and Roelich, 2021). While the focus has been on new infrastructure, these same issues apply to renewal programmes, especially where these involve the renewal and upgrades to long lived infrastructure.

While this captures new infrastructure and major renewal programmes, there is a further set of actions needed, to address other infrastructure assets that might be at high climate risks (i.e., where targeted action is needed). This is an important issue in the UK, due to the very large levels of existing (legacy) infrastructure, much of which was built in the 1970s onwards, and thus is not designed for the future climate. This involves additional issues around safety.

Complementing the above, there is increased interest in transport network adaptation. This adopts a more systemic approach, that can look at climate risks across a network (for an example, see Oh et al., 2020), including both direct and indirect effects. This then allows the analysis of adaptation prioritisation to a network rather than for individual assets, for example, focusing on hotspots where adaptation is most urgent. This can extend to issues such as multimodal connectivity.

Finally, transport adaptation should not be seen as only a set of technical measures, it also relies on the information and processes for decisions. This links to design standards, climate

risk screening in public and private investments, disclosure, as well as weather and climate services and insurance.

Scope of a Well Adapted UK

The CCC adaptation monitoring map for a well-adapted transport system is shown below.

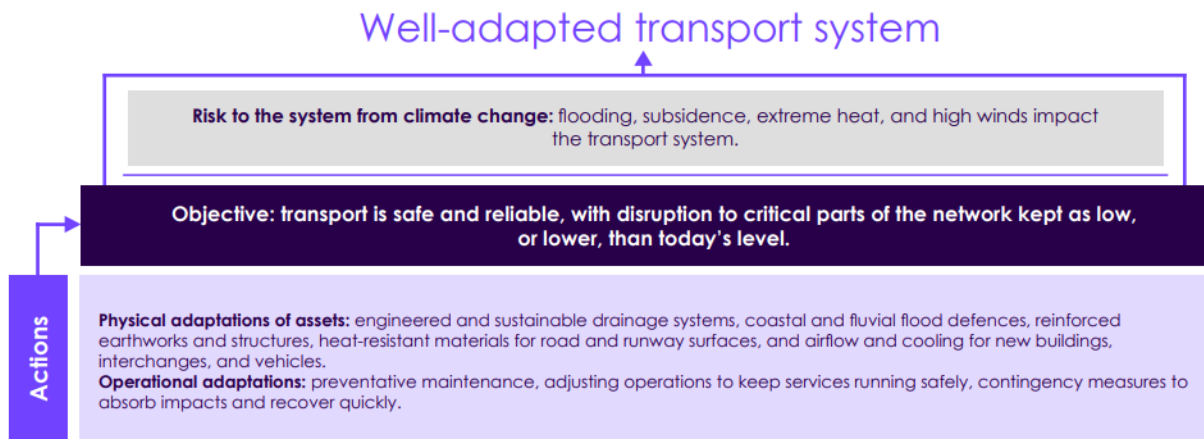


Figure 4 Scope of a well-adapted transport system. Source: Climate Change Committee

Linking back to Figure 1, there are alternative objectives that can be set for this well adapted transport system. This could be based on the economic optimal level, based on an analysis of costs and benefits. It could alternatively focus on objectives on the level of service provision and acceptable levels of disruption. These can be expressed in terms of a current acceptable level of performance, as set out for rail operators (noting implicitly, these consider the additional costs versus the benefit of reduced lost time from travel time disruption, though these are likely to be different if set on current levels than the future economic optimal level).

However, setting objectives for transport infrastructure cannot be seen as a purely economic decision. For example, for the railways, there is the risk of major accidents involving loss of life, and therefore safety and duty of care issues. Such events have happened in recent years, notably the Stonehaven landslide and fatalities and the recent Shap derailment. However, there is a very large difference in the standards set, reflecting the climate risk profile between a central projection (50th) and a high projection (95th percentile for a high emission pathway), e.g., this can double peak rainfall flows, see Dale, 2019) and can have a major feed through to adaptation costs. This also leads to the potential for economic maladaptation, by climate proofing for projections that are unlikely to be realised, or realised late in the century beyond the economic lifetime.

There are also questions of whether entire networks are adapted or different approaches are used for different assets within the system. For example, where transport infrastructure might merit a higher level of precaution, there may be a strong case for climate over-design, such as with bridges.

This highlights that the definition of adaptation goals and objectives are political, and will need to reflect societal preferences (on willingness to pay for adaptation, as well as willingness to accept risks). These will also require consideration of the appropriate cost sharing mechanisms, i.e., who pays. This will be reflected in turn in public funding for transport adaptation, as well as the costs for users (e.g., road duty, rail fares).

The CCC have also identified potential actions to investigate for the well adapted analysis, reported in the box below. However, assessing these actions would require detailed bottom up modelling, at the national scale. This would need to be aligned to the CCRA4 scenarios, and the levels of global warming in different periods (CCC, 2024; Jaroszweski and Dawson, 2025), including the central scenario and a high climate hazard scenario. This would be a major piece of analysis, first in terms of the physical risk analysis, but then also in terms of the costs and benefits of adaptation.

Box 1. Potential adaptation actions for transport selected by the Climate Change Committee

Physical adaptations: drainage (engineered and sustainable drainage systems), flood protections, stabilising earthworks, heat resistance (such as through use of more durable materials), and reinforcing structures to withstand high-winds.

Operational adaptations: preventative maintenance, adjusting operations (such as through altered service schedules), contingency measures.

Further information can be found in Chapter 10 of the CCC's Well-Adapted UK Report.

In the absence of this level of analysis, this study has used a **top-down approach**, using investment levels and **adaptation cost mark-ups**. This is a common method in the literature and has been applied in many studies, e.g., in national studies in France, Germany (Depoues and Dolques, 2024; Holscher et al., 2026) and the EU (Neumann et al. 2026) and in studies in developing countries (Hallegatte et al., 2019a: 2019b).

These allow indicative estimates of the costs of adaptation by applying a % uplift to infrastructure investment pipelines (e.g. OECD, 2015). These mark-ups can be taken from ex post analysis of the cost of climate proofing investment (e.g., see ADB, 2014) or from engineering estimates of cost mark-ups (e.g., see Miyamoto International, 2019). They allow some analysis of potential costs, but they also have limitations. First, there is a range from the various cost-mark-up studies, and the choice of uplift has a large influence on the final adaptation costs. Second, they do not consider the site or context specific nature of climate risks, nor the benefits avoided, and thus they do not represent an economically optimal level of adaptation. They are also influenced by the future investment and renewal programmes, and thus may be limited by finance allocations rather than actual needs.

Analysis of transport adaptation costs

It is difficult to establish current adaptation costs in the transport sector, because it is difficult to separate out and attribute the element of adaptation costs from broader transport investment. For example, while there have been changes to design standards and materials for road infrastructure, it is not possible to precisely identify the incremental adaptation cost from the broader investment cost. In cases where design standards have already been changed, these adaptation costs may be already internalised, but this does not mean they do not exist. The costs of building a road today with higher standards is greater than if climate change had not happened, so these cannot be ignored, but it is difficult to establish counterfactual to separate these out.

Rail

The UK's railways are extensive, comprising of 20,000 miles of track, 30,000 bridges, viaducts and tunnels, and 200,000 slopes in Britain (DfT, 2024). There is some data on current adaptation spend for the railways, from control period submissions from rail network operators to the rail regulator (the Office of Road and Rail).

Current adaptation spending

Network Rail set out their investment plans in their strategic business plan for England and Wales for the five year Control Period (CP7) (covering April 2024 to March 2029) (Network Rail, 2023). This had an initial estimates of proposed funding (for operation, maintenance and renewals of rail infrastructure over the 5 year period) for weather resilience activities and climate change adaptation (earthworks and drainage renewals, and maintenance activity⁴). This was subsequently updated in the regional plans for 2024-2029 was subsequently published (Network Rail, 2024a). This estimated that £2.8bn (over the 5 year period) for Great Britain for weather resilience activities and climate change adaptation (earthworks and drainage renewals, and maintenance activity). This breakdown is shown below. These actions are split into two categories. The first are pure weather resilience activity, undertaken solely to make the railway more resilient to extreme weather – around 55% of these costs are for earthwork and 23% for drainage. The second are business as usual activities with weather resilience benefits, where activities are driven by poor asset condition and extreme weather and climate change challenges, so that the work improves both the asset’s condition and its weather resilience. In this analysis we attribute 100% adaptation costs to both, but there could be a lower attribution to the latter. The breakdown is shown in the Table below.

The overall figures was revised down to **£2.6bn** (5.91%) in the 2025 update (Network Rail, 2025). These figures imply current adaptation costs/needs of approximately **£520 million per year** for the Great Britain rail network over the current five year period.

Table 2: Summary of expenditure on primary resilience activities and strategic weather and climate resilience projects for CP7. Source: Network Rail (2024a).

Region/Function	£million over 5 year period						
	Wales and Western	Southern	Eastern	N. West and Central	Scotland	National Functions	Total
Asset activities with primary resilience benefit	409	627	409	524	352	0	2321
Other weather and climate resilience (e.g. Strategy, tools, taskforce)	38	152	5	157	4	112	468
Total	447	779	414	681	356	112	2789

Network Rail also is also working to develop estimates of future adaptation and resilience costs for the next two periods FP1 (2029–2034) and FP2 (2034 to 2039), but the levels will be determined through the funding review process (noting the needs for a well-adapted objective could be different from funding allocations). Furthermore, across the UK, Network Rail is implementing a flagship programme - the adaptation pathways programme – which uses an adaptive management approach to assess climate risks and identify the most appropriate risk management options for a particular area (at a particular time). This will influence future adaptation and resilience cost estimates. .

In Scotland, the Climate Ready Plan (Scotland’s Railway, 2024) (2024-2029), combined a top-down allocation and bottom up, engineer-led approach to estimate the potential adaptation needs. The bottom up analysis resulted in a higher total investment costs to £434 million over the 5 year of control period 7. For this analysis we use the Network Rail values in Table 2. Network Rail Scotland is also undertaking work to estimate potential adaptation and resilience investment for CP8 and CP9. The levels will be determined through the funding

⁴ Increased maintenance costs are, strictly speaking, an impact not an adaptation cost.

review process, but under some scenarios when major capital investments are included, then adaptation costs could be much higher than current periods.

In Northern Ireland, similar analysis is underway by TransLink to look at future adaptation and resilience costs, based on a similar approach to the Network Rail approach. Discussion with TransLink did identify they are experiencing increases in maintenance costs already, and that there will be additional capital costs, especially if this extends to tackling the large number of assets at risk.

There are also a separate set of additional costs associated with High Speed Rail 2. This project is an extremely large capital investment (e.g. capital and resource expenditure in 2024 – 2025 was £7 billion alone). The project has increased the design standards to ensure HS2 is climate resilient (see HS2 3rd round ARP (HST, 2022) and (HS2, 2024). This includes protecting to a 1 in 1000 year flood (historic climate) and including climate change uplifts in the drainage standard (1 in 100 year plus Environment Agency climate change allowances), as well as increased heat uplifts for stress-free temperature for slab tracks. This is an increase in the design standard compared to historic and translates into higher costs (compared to the counterfactual). However, the costs of implementing these higher design standards is not split out / known by HS2. It is stressed that these design standards are already included in procurement, so these higher costs are already internalised.

A further set of adaptation costs will be associated with the London Underground and other urban systems. There is an analysis of risk in the ARP4 (TFL, 2024) and this includes some analysis of TfL funding of adaptation measures from the GLA Group's climate budget, though this indicates very modest funding of a few million annually. There will also be climate proofing costs associated with extensions (as in many UK cities), as well as plans for new systems (e.g. in Glasgow City Region).

There will also be some adaptation costs for train companies, associated with managing weather and climate related risks, but these have not been assessed.

Future adaptation costs

The climate impacts and thus adaptation costs in future periods beyond 2030 are likely to be higher (based on the higher magnitude scores in CCRA4). These arise from increased climate proofing of new capital investment and targeted retrofitting of existing sites, as well as operational measures. As highlighted above, network operators are currently going through future costing exercises, but no data is yet available. Given the lack of published information it is difficult assess future adaptation costs robustly. However, to provide some indicative estimates, two approaches have been used.

Scaling current control period estimates. There are current CP costs reported, and future CP8 (FP1) and CP9 (FP2) assessments are underway. Given the projected increase in risks in CCRA4, and based on discussions with rail operators, adaptation and resilience costs are likely to be higher in future decades as compared to current, from the combination of climate proofing new capital investment and renewals, and from tackling the high risk sites across the network (railway lines, cuttings and embankments, bridges, etc.). It is possible to provide indicative estimates of future costs by scaling current A&R spending.

Adaptation mark-ups on future investment levels. An alternative approach is to use adaptation mark-ups. This starts with the projections of total future rail investment, for new and renewal programmes, from the National Infrastructure Commission out to 2040 for England (NIC, 2023). These can be combined with adaptation mark-ups to assess the potential level of adaptation investment for these future investment levels. These mark-ups

are based on the engineering literature on the incremental climate proofing costs from project design e.g., see Miyamoto International, 2019) and from technical project preparation studies, especially from the multi-lateral development banks, which track the incremental adaptation for climate finance tracking (e.g., ADB, 2022). In practice, these mark-ups vary strongly with the hazard profile of the track, and the number and risks to structures and earthworks. This range was used to provide an indicative analysis of future adaptation costs. The lower range from the mark-ups is similar (though slightly) below the current investment in adaptation and resilience in CP7 shown in the Table above, providing some degree of validation. The upper range was significantly higher (2 – 3 times higher). The values derived for England were then extended to Great Britain assuming a similar ratio to CP7 figures, and cross checked with a similar approach being undertaken for Scotland (ClimateXChange analysis, Brett et al., forthcoming). The estimates are shown for Great Britain in the Table below. It is stressed that these are indicative only. These values would rise with the addition of Northern Ireland.

It is stressed that in later decades, especially for higher warming scenarios, there could be potentially much higher cost to address the very large stock of assets across the network, noting this involves issues of safety (not just the economic optimal level of adaptation). The Network Operators are assessing the asset risks across their networks and identify significant numbers of assets which are at risk (especially for 4°C pathways) and which will be very costly to retrofit. As an example, Dawson et al. (2018) explored the costs to address coastal erosion and sea level rise risk on the London to Penzance line at Dawlish⁵. A further restrengthening of flood defenses was estimated at a total costs £528m over a 20-year period while the construction of a new inland route was estimated at a total cost of £2182m. There are similar high risk lines in all DAs.

Table 3 Indicative estimates of rail adaptation costs for Great Britain. (£/year)

Scenario	Current	2030s	2040s	2050s
Rail operator CP submissions*	£520 million/year	Discussion indicates likely <£520 million/year		
Future rail central estimate** (new and renewal)		£470 million - £1,460million/year	Not quantified	Not quantified
Future rail high estimate including existing assets		Not quantified but could involve much higher costs, due to the retrofit challenge for adaptation of existing assets, especially for high warming scenarios (including safety)		

* Based on submitted CP7 from Network Rail (2024).

** Source Authors. Range based on modelling of future rail investment (new and renewal) from NIC combined with adaptation cost uplifts from literature, adjusted to GB. Range reflects adaptation mark-ups from literature. NIC projections used as analytical baseline for the modelling in this report, and are not produced by Network Rail.

For the CCC analysis, a single number is used. For this, we assume the mid-point value as an average across the period.

Road

There is a large road network in the UK, reported at 187,000 miles for England alone (DfT, 2024). There is less data for **road** adaptation costs than for rail, with no current published spend estimates, and the information that does exist tends to focus on the strategic road network (motorways and major A-roads).

⁵ Note that there has been an £80 million project at Dawlish completed in 2023 which included an eight metre high sea wall (See Network Rail, 2024b) though

The Strategic Road Network in England is the responsibility of National Highways (formerly Highways England / Highways Agency). This has set out its approach to building climate resilience in Adaptation Reporting Power reports (see ARP4, National Highways 2024). National Highways do not publish a single standalone figure for adaptation expenditure in the ARP, as climate resilience measures are embedded across asset renewals, maintenance, design standards, operations and major projects⁶.

There is climate risk and adaptation investment, and National Highway is at a mature level of adaptation, having developed an approach that takes account of asset lifetime (ARP1, see figure 3 in earlier section), developed asset level climate risk assessments (ARP3/ARP4), and integrated climate projections within drainage, geotechnical, pavement and structures strategies, and weather related forecasting and response.

The Strategic business plan (Highways England, 20-25) set out the total road investment programme, which totalled £27.4 billion over the period. This does identify historic investment of £0.5 billion in environmental investments, but these include multiple components and are not limited to climate adaptation (though they do include flood alleviation). The plan did not provide separate estimates of adaptation spend for the 20-25 period.

Within the DfT's 2025 climate adaptation strategy for transport there is a commitment to put greater emphasis on climate risk management and long-term adaptation plans in the third Road Investment Strategy (RIS3, 2026-2031). The Draft Road Investment Strategy 3 (2025) document outlines how it is essential that the road sector plays its part in being resilient to the effects of a changing climate and that RIS3 will be fully integrated with the Government's wider climate and environment objectives. National Highways is proactively assessing climate risks as part of RIS3 development. However, as RIS3 discussion are underway currently, there is no published information.

Local roads are overseen by Local Highway Authorities and comprise a much larger length of roads. These are typically less well maintained than the strategic road network and there is a large and growing backlog of maintenance and renewal needs (estimated according to industry estimates at £15.6 billion, see HMT, 2025). There is little information on the potential adaptation costs.

There have been changes to road design to recognise climate risks, with guidance in the Design Manual for Roads and Bridges (see LA 114 – Climate, HA, 2021). It might be possible to gather information on the cost implications of these changes, but this would require more analysis, though this is recommended as a future area of investigation.

The Strategic Road Network in Scotland is the responsibility of Transport Scotland. There is some information available for Scotland from a study on the potential costs of adaptation for the Scottish Trunk Road network (Jacobs and AECOM, 2022) as part of the Scottish Government's Strategic Transport Projects Review 2 (STPR2). This estimated that the costs could £1bn - £2.5billion over the twenty year lifetime of STPR2 (2022-2042). Expressed annually these indicate a range between £50m/yr to £125m/yr, but this estimate is not considered robust by the Scottish Government. It is primarily based on the adaptation needed to address flooding in highly exposed locations.

⁶ There is a reference to a collaborative programme to address flooding and water quality with the Environment Agency (EA) with a combined value of £23 million. The report also documents the approach of climate adaptation roadmaps which provide timelines and ownership for implementation of our updated adaptation actions.

Due to the lack of published information it is difficult to assess future adaptation costs robustly. This analysis has therefore developed estimates but it is stressed these can only be considered indicative, and further work is needed to develop robust values.

A literature review identified a limited number of studies on potential adaptation costs for roads in the UK. The DfT rapid evidence review (Steen et al., 2022) on transport adaptation costs and benefits identified some cost estimates. This included Altavar et al. (2012), a European study that included UK estimates. This included some high values, e.g., it estimated updating UK roads to use a type of asphalt to cope with increased temperatures at between €254m and €763m per year, though there is no evidence to support this level of costs. Atkins (2013) looked at the potential risks of climate change on pavements and road bridges and estimated the costs and benefits of addressing additional heat impacts, for a central and worst case scenario, though reported total present value costs not annual costs⁷. Costs were six times higher under the worst-case scenario, but found positive benefit to cost ratios for both scenarios.

In the absence of detailed quantitative studies, adaptation cost uplifts have been used to produce indicative costs. This draws on the projections of total future road investment, for new and renewal programmes, from the National Infrastructure Commission out to 2040 for England (NIC, 2023). It is stressed that NIC projections were used as an analytical baseline for the modelling in the report, and are not produced by National Highways or other road authorities. These future investment profiles were combined with adaptation mark-ups to assess the potential level of adaptation investment for these future investment levels. These mark-ups were based on the engineering literature on the incremental climate proofing costs from project design e.g., see Miyamoto International, 2019), literature review (e.g., Atkins 2013) and from technical project preparation studies, especially from the multi-lateral development banks, which track the incremental adaptation for climate finance tracking (e.g., ADB, 2022). These adaptation cost uplifts will clearly vary in practice according to a large number of factors, associated with the hazard profile, the nature of the investment (e.g., new or renewal, number of bridges). For example, Atkins (2013) report the cost uplift for more heat resistant surfacing to be 15%. ADB (2015) cites experience from road projects (multiple hazards) indicate an increase of 0.5 to 8.7% (of total new build / major renewal project cost) and there are generally uplifts of 5% to 15% cited in Miyamoto International (2019). These uplifts are then applied to investment profiles or new roads and renewals (for both major and local roads). A similar approach was undertaken for Scotland (ClimateXChange analysis, Brett et al., forthcoming). The results are shown in the table below, but it is stressed that these numbers can only be considered indicative. The mid-point is used for the CCC summary.

It is highlighted that a larger share of adaptation costs falls to local roads, where funding to date has been more constrained and there is a large investment backlog, and as such the values reflect needs (and are higher than if assessed based on historic flows). It is also noted that in later decades, especially for the CCC higher warming scenarios, there could be potentially much higher costs to address the very large stock of assets across the road network, noting this involves issues of safety (not just the economic optimal level of adaptation). A more ambitious programme might factor in more additional targeted actions to address risks to existing infrastructure, leading to much higher costs.

⁷ The discounted costs over a 60 yr period costs of adaptation measures were estimated at £6.4 million under a central scenario (A1B - 2.8C by 2100) and £41 million under a worst case scenario (A1FI - 4C by 2100) for pavements and bridges alone, but annual undiscounted figures are not provided.

Table 4 Indicative estimates of road adaptation costs for Great Britain. (£/year). Source authors.

Scenario	Current Period	2030s	2040s	2050s
Strategic road network	Not available			
All road# central estimate (new and renewal)##		£425 million - £1,110 million/year	Not quantified	Not quantified
All road high estimate including existing assets		Not quantified but could involve much higher costs, due to the retrofit challenge for adaptation of existing assets, especially for high warming scenarios		

Includes strategic road network, local roads, and London and other urban areas.

Based on modelling of future road investment (new and renewal, for all road classifications) from NIC combined with adaptation cost uplifts from literature (authors), and equivalent analysis for Scotland (Brett et al., forthcoming). Range reflects adaptation mark-ups from literature. NIC projections were used solely as an analytical baseline for the modelling in the report, and are not produced by National Highways.

Ports, airports and waterways

There is much less information on ports and airports, because these are privatised systems in the UK.

Given their location in coastal zones, low-lying areas, ports are at risks from climate change. There are a range of adaptation actions that have been identified (see PIANC, 2020). This includes measures to address weather related disruption, climate proofing of new ports (and upgrades and retrofitting) as well as addressing risks to connecting infrastructure. It includes soft options such as improved weather information and emergency management planning, understanding port-specific climate and supply chain impacts, and implementing contingencies to restart operations as quickly as possible, as well as hard options such as elevating, relocating or protecting.

When looking at potential adaptation costs, it is important to note that adaptation measures taken by individual private ports are unlikely to be optimal from a societal perspective. This is because of various market and policy failures e.g., the positive externalities of reducing wider impacts across the economy from reduced port disruption. There is some actions that is reported in CCRA3 and CCRA4 where ports have been proactively raising quay heights and assessing interdependences. There is also an example of hard adaptation measures taken, for example, the Port of Immingham raised protection to a 1/1000 year flood protection level, up from a 1/20 year flood previously, as a result of the 2013 storm, at a cost of approximately £5m (Associated British Ports, 2016). It might be possible to derive a national value by scaling up similar investment costs for all ports.

A number of international ports have developed adaptation plans, and there are some cost information from new projects, such as in Morocco (EBRD, 2017), and the Port of Rotterdam in the Netherlands (Port of Rotterdam, 2021).

A review of the port operators reports submitted under the Fourth Adaptation Reporting power reporting period does not provide any information on specific actions and costs or planned investments from port operators. However, some information can be gained from reviewing international efforts. There costs of some of these investments can be very high, and can be non-linear if extreme sea level rise is taken into account (e.g., for retrofitting or new build ports if higher SLR projections are used). This has led to more of a focus on

iterative adaptation, with measures that allow the potential for more extensive investments in the future (Cooke islands one).

There are also potential risks to other waterways, though these tend to receive less attention. This includes navigable rivers and lakes and the canal system.

Overall assessment of adaptation costs for transport

Projections of future transport investment and adaptation costs were included in the NIC National Infrastructure Assessment (NIC, 2023). This included climate proofing costs for road and rail renewals (but not new infrastructure) but only starting in 2030. This estimated costs were £150 million/year for road and £400 million/year for rail renewals.

For this study we have undertaken a more detailed analysis, though this should still only be considered indicative. This has looked at the current submissions for adaptation and resilience spending for the railways (no equivalent data exist for road). It has also looked at future adaptation and resilience costs by looking at future investment levels from the National Infrastructure Delivery Plan, the new UK infrastructure pipeline^{8,9} and the investment profile from the NIC National Infrastructure Assessment (NIC, 2023). These investment flows were combined with a disaggregated set of transport adaptation mark-ups piled, for each type of investment (road renewal, road new, etc).

These lead a central range estimate of approximately £0.95 billion to £2.57 billion per year for the 2030s for the Great Britain road and rail networks. It is stressed these numbers are highly indicative only. These costs are likely to rise in the 2040s and 2050s, especially for high warming scenarios, and particularly to address existing assets. There are no robust data for ports and airports.

These numbers can be benchmarked to other studies. At the European level, the European Environment Agency has recently estimated the costs of making agriculture, energy and transport, estimating these at between EUR 53bn and 137bn annually by 2050 (Neumann et al. 2026), of which EUR 9bn to 20 bn was for transport (EU27). On a GDP basis, this would imply very approximate costs for the UK of 1.5 to 3bn per year.

This analysis does highlight the large evidence gap. There are existing research programmes that are starting to build the evidence¹⁰

⁸ <https://pipeline.nista.grid.civilservice.gov.uk/introduction>

⁹ There is a new UK Infrastructure Pipeline which contains data on around 780 projects and programmes from the public and private sectors planned over the next ten years, totalling around £530 billion of which 14% is transport, but there are no capital or renewal costs for road in the detailed pipeline. There is also a Scottish Infrastructure Delivery Pipeline 2026, which includes £4.7bn of road improvements as well as £1.4bn of improvements in bus infrastructure, active travel, smart cards and EV charging, and £1.7bn of rail improvements. Welsh Infrastructure Investment needs are set out in the Welsh Infrastructure investment Pipeline (Welsh Government, 2025) . This identifies £1040m of road infrastructure investment, and £1180m of rail investment. Northern Ireland's pipeline is maintained by Investment Strategy Northern Ireland (ISNI, 2025). This provides an overview of the next five years or projects contributing to the 2050 infrastructure strategy for Northern Ireland (Northern Ireland Executive, 2022) . Analysis of the 'networks' pillar suggests a range of investment between £737.3m and £861.6m.

¹⁰ For example, for Rail, there have been a number of major initiatives, with RSSB (Tomorrow's Railway and Climate Change Adaptation) as well as the network operators, and research continues with the DARE [Hub](#) and Spark [Hub](#).

Table 5 Indicative Adaptation Costs for Transport in Great Britain (£/year). Source authors..

Scenario	Current	2030s	2040s	2050s
Rail operator CP submissions	£520 million/year			
Future rail central estimate (new and renewal)*		£520 million - £1,460 million/year	Not quantified	
Future rail high estimate including existing assets		Not quantified but could involve much higher costs, due to retrofit challenge for adaptation of existing assets, especially for high warming scenarios		
Road operator submissions	No data available			
Future road central estimate (new and renewal)*		£425 million - £1,110 million/year	Not quantified	
Future road high estimate including existing assets		Not quantified but could involve much higher costs, due to retrofit challenge for adaptation of existing assets, especially for high warming scenarios)		
Ports	No data available	Not quantified	Not quantified	Not quantified
Airports	No data available	Not quantified	Not quantified	Not quantified
Inland waterways	No data available	Not quantified	Not quantified	Not quantified
TOTAL central estimate#	Not known	£945 million - £2,570 million/year	Not quantified	Not quantified

See earlier tables for notes.

*Source authors based on adaptation mark-ups and NIC projections. The range reflects range from the literature. Note that NIC projections are used as analytical baseline for the modelling in this report, but are not produced by Network Rail or National Highways.

road and rail only.

Benefits of transport system adaptation

There is some evidence on the economic returns of transport adaptation. The most frequently cited evidence in the literature is the World Bank study on climate proofing infrastructure, including road and rail (Hallegatte et al., 2019a: 2019b), which reports a benefit to cost ratio of 4:1. However, a more detailed analysis of this work shows a more nuanced finding. First, the analysis assessed two scenarios: one where there is perfect site-specific knowledge on hazards (now and in the future) and thus design and standards are targeted only at vulnerable infrastructure, and another where this information is unknown and general standards are applied to all infrastructure. The latter involves much higher additional costs. Further, the BCRs vary quite significantly. While most indicate BCRs>1, there are some which fall below.

Similar issues also apply to much of the literature. Most studies assume perfect foresight, and this provides more optimistic projections of economic returns. In practice, actions will not be optimal due to deep uncertainty, meaning there is always an over or under allocation of resources. For example, a study on rail embankment resilience (Reeves et al., 2013) in the UK found negative net present values. The earlier study by Atkins (2013), which looked at heat for roads, found the benefit to cost ratios was only 1:1 (central) though this rose to 2.6:1 (high warming scenarios).

A number of these issues can be tackled with improved information and targeting, as is being advanced in both road and rail sectors with adaptation pathway approaches.

Land System

This supporting rapid research aims to investigate the potential costs for the UK land system. This covers biodiversity (terrestrial, freshwater and coastal), as well as farmland, woodland and uplands.

Climate risks and future damages for the land system

There are a very large number of potential climate change risks to the land system. These include the potential risks to natural capital and ecosystems services, including provisioning, regulating, cultural and supporting services.

The risks of climate change to the natural environment were set out in the CCRA3 nature theme (Berry and Brown, 2021). Watkiss et al. (2021) assessed the potential economic costs of these, shown below, but the economic costs of many important risks were unknown. This reflects the uncertainty around the physical impacts of climate change, as much as the uncertainty around the economic valuation of these impacts.

Table 6. Economic Valuation of Risks and Opportunities for the Natural Environment CCRA3.

Risk / Opportunity	Present Day	2050s	2080s, 2°C	2080s, 4°C	Confidence
NE1. Risks to terrestrial species and habitats from changing climatic conditions and extreme events,	Unknown	Unknown	Unknown	Unknown	Low
NE2. Risks to terrestrial species and habitats from pests, pathogens and invasive species	Unknown	Unknown	Unknown	Unknown	Low
NE3. Opportunities from new species colonisations in terrestrial habitats	Unknown	Unknown	Unknown	Unknown	Low
NE4. Risk to soils from changing climatic conditions, including seasonal aridity and wetness.	H	H	H	H	Low
NE5. Risks to natural carbon stores and sequestration	VH	VH	VH	VH	Low - med
NE6. Risks to and opportunities for:					
<i>Agriculture</i>	L - H	H +H	VH +VH	VH +VH	Low
<i>Forestry</i>	(variability)	L - H	L - H	L - H	Low
NE7. Risks to agriculture from pests, pathogens and invasive species	M	M	H	H	Low
NE8. Risks to forestry from pests, pathogens and invasive species	M	M	M	H	Low
NE9. Opportunities for agricultural and forestry productivity from new/alternative species	+M	+H	+H	+VH	Low
N10. Risks to aquifers and agricultural land from sea level rise, saltwater intrusion	L	Unknown	Unknown	Unknown	Low
N11. Risks to freshwater species and habitats from changing climatic conditions and extreme events	H	H	H	H - VH	Low
N12. Risks to freshwater species and habitats from pests, pathogens and invasive species	L	L	L	M	Low
N13. Opportunities to freshwater species and habitats from new species colonisations	+L	+L	+L	+M	Low
NE17. Risks and opportunities to coastal species and habitats due to coastal flooding, erosion and climate factors	L	M	M	M	Low
NE18. Risks and opportunities from climate change to landscape character	Unknown	Unknown	Unknown	Unknown	Low

Key

Risks	Opportunities	
VH	+VH	£billions/year
H	+H	£hundreds of millions/year
M	+M	£tens of millions/year
L	+L	£<10 million/year

The CCRA4 consultation chapter land, food and nature (Bullock et al., forthcoming) identifies risks, and generally reports these are higher than for CCRA3.

Table 7. Provisional scoring in CCRA4 land, food and nature (Bullock et al., forthcoming).

Risk	Present	2030	2050	2080	Urgency
N1. Risks to terrestrial and coastal ecosystems	H	H	H	VH	CI/MAN
N2. Risks to freshwater ecosystems	H	H	H	VH	MAN
N4. Risks to soil ecosystems	M	M	H	H	CI
N5. Risks to natural carbon stores & sequestration	H	H	H	VH	CI/MAN
N6. Risks to agriculture	H	H	H	VH	MAN
N7. Risks to fisheries and aquaculture	H	H	H	VH	MAN
N8. Risks to forestry	H	H	H	VH	MAN
N9. Opportunities for agriculture, fisheries, aquaculture and forestry	L	L	L	L	FI

CAN = Critical Action Needed, CI= Critical Investigation. MAN = More Action Needed, FI = Further Investigation, SCA = Sustain Current Action

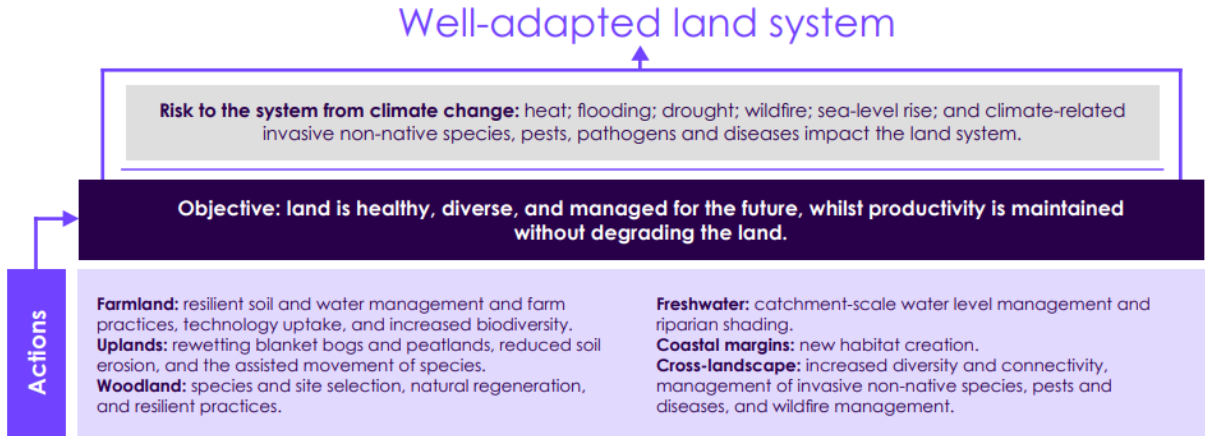
Assessing adaptation costs and benefits for the land system

In theory, an analysis for the land system would assess future economic costs from climate change then assess the costs and benefits of addressing these specific climate change related impacts (see Figure 1). However, in practice, there is not good information on these economic costs, and even less on the effectiveness of adaptation in reducing them. Furthermore, there are multiple drivers and pressures on the land system, and trying to unpick climate change risks from other non-climatic risks is extremely challenging. Current and future risks are also highly influenced by future land policy and management practices and climate risks need to be in the context of the multi-functionality of land systems.

This means that the identification and costing of adaptation is extremely challenging. Linking back to Figure 2, in most cases, interventions in this area have multiple objectives, e.g., protecting biodiversity, reducing GHG emissions, reducing environmental pressures, as well as adaptation. This means some level of attribution is needed to allocate costs to adaptation as compared to other objectives.

Scope of a Well Adapted UK

The CCC system map for a well-adapted land system is shown below. This brings together previous monitoring maps on i) nature and ii) working land and seas (CCC, 2023). For this analysis, there is a separate analysis of seas, and the coverage here has been focused on five areas: coastal margins, freshwater and fisheries, farmland, woodland and uplands.



The CCC have also identified potential actions to investigate for the well adapted analysis, shown in the box below.

Following the discussion above, many of these actions are not specifically targeted at climate risks, or at climate risk alone. The analysis here has therefore tried to be more specific with respect to attribution.

Box 2. Potential adaptation actions for land selected by the Climate Change Committee.

An example of a target: by 2030, 30% of land should be protected for nature and by 2050 should be in good condition.

Cross-landscape actions: Increase diversity and connectivity, manage INNS, pests, pathogens and diseases, wildfire management.

Farmland: Uptake of resilient soil and water management practices, changing the type or timing of farm practices, technology and precision farming, increasing on-farm biodiversity to support nature to adapt.

Uplands: Rewet blanket bogs and peatlands, minimise soil erosion, assisted movement of species.

Woodland: Species and site selection for future climate, natural regeneration of woodland, resilient woodland practices.

Freshwater: Catchment-scale management of water levels for freshwater habitats and riparian shading to reduce water temperatures.

Coastal margins: Create new coastal habitat to offset that lost through coastal squeeze.

Further information can be found in Chapter 13 of the CCC's Well-Adapted UK Report.

The work has drawn on extensive previous work undertaken in these areas, but we stress that given the challenges involved, the estimates below should only be considered indicative.

NAP3

There were a significant number of actions reported in NAP3 for the natural environment theme, which correspond closely to the land system. These included many of the actions in the 25 Year Environment Plan (25YEP) (HMG, 2018) and updated in the Environmental Improvement Plan (EIP) (Defra, 2023). However, most of these were not costed. It is also highlighted that some of these targets have changed, as set out in the EIP2025 (Defra, 2025).

Biodiversity (nature, natural capital, ecosystem services)

Defra collates values of current **biodiversity** spend. In 2023/2024 around £887m of public sector funding was spent on biodiversity in England. However, it is extremely difficult to attribute how much of this funding goes to adaptation related actions.

The NAP3 had a strong focus on the **biodiversity policy targets** for England as set out in the 25 Year Environment Plan (25YEP) (HMG, 2018) and updated in the Environmental Improvement Plan (EIP) (Defra, 2023). NAP3 included the 30 by 30 targets, with the goal to halt the decline in species abundance by 2030 and protect 30% of land in England in a way that recognises and responds to climate change risks by 2030 to reduce the risk to terrestrial species and habitats. NAP3 also included the 25 YEP and EIP targets for restoring and creating over 500,000 hectares of wildlife-rich habitat outside of Protected Sites by 2042, including 140,000 hectares by 2028, and restoring 75% of Protected Sites to favourable condition by 2042.

The 2023 EIP was formalised in the Environment Act and its biodiversity targets and included four specific actions of i) restoring protected sites to favourable condition; ii) increasing

species abundance; iii) reducing the risk of species extinction; and iv) creation/restoration of wildlife-rich habitats outside of protected sites. Some of these included targets or interim targets for 2030 and others for 2042 (the 25 year plan period).

There were several iterations of the Government impact assessment (IA) – the economic analysis undertaken alongside the proposals - for delivering the Biodiversity targets. The costs of meeting the objectives changed with the specific target. The draft Defra impact assessment (Defra, 2022a) was based on a commissioned study (IFC and Eftec, 2021) that assessed the costs¹¹ of meeting the proposed biodiversity targets would be £1040m/year over the 25YEP period (£1090Bn/year in current prices)¹². It assessed that 73% of this would come from the public sector (£0.796Bn) and the IA presented the incremental spend over current biodiversity public spend. However, these costs vary with the exact targets chosen, i.e., the % of sites in favourable conditions, the hectares of wildlife rich areas. The Defra final impact assessment was published at the end of 2022 (Defra, 2022b). The impact assessment also looked at the economic benefits of these targets, identifying a benefit to cost ratio of 3.1:1 in the low benefit scenario and 5.5:1 in the high benefit scenario.

Supporting work for the impact assessment included an analysis of the **adaptation costs to ensure these biodiversity targets could be met under a changing climate** (Watkiss, Berry and Hunt, 2021). This included detailed analysis of each of the four biodiversity targets, using supporting studies to assess the impact of climate change on protected areas and adaptation costs, the risks of climate change to red list species and associated adaptation cost to address these risks, and the costs of adaptation to make actions for increasing species abundance and wildlife rich areas climate-resilient. These include many actions which are included in agro-environmental schemes, for example, creation of woodlands species-supporting habitats such as hedgerows. These will be incentivised through land management (and ELMS), and these costs are included in this biodiversity section, and not replicated in the agriculture and farming section later, to avoid double counting.

This supporting adaptation analysis to the IA concluded that climate change was likely to affect the achievability of the proposed biodiversity targets and could lead to a significant cost increase for their delivery. A detailed economic analysis was undertaken of the additional cost of meeting each of the four targets under climate change. The additional costs were estimated at £200 million/year (with a range of £170m to £255m per year (2020 prices) depending on the ambition level) averaged over the 25YEP period to 2042. This was a 20% increase on the baseline IA spend, rising to 25% with higher ambition (though the relative increase varied with each target). This would be £200 m to £300m/year in current prices. The economic analysis supporting the IA found that adaptation would maintain or even increase the benefit to cost ratios for the biodiversity targets. It is noted that the targets were not set at the optimal level (where marginal costs are equal to marginal benefits), and therefore a higher level of action might still be (economically) justified.

For this analysis, we have gone back to the original IA adaptation analysis. This included a more detailed analysis looking at costs up to 2030 and separately onto 2042, for two different

¹¹ The underlying IA was built on a study by IFC and Eftec (Costs and Benefits of England's Biodiversity Ambition). This focused on programmes of action that could reasonably deliver the targets, and was focused on creation and restoration costs. It did not include potential opportunity costs, which would potentially be relevant for some actions outside protected areas.

¹² Defra updated the EIP in 2025 (Defra, 2025). This published commitments to the 30 by 30 goal, and commitments for 250,000 hectares of a range of wildlife-rich habitats outside of protected sites by 2030, to increase England's tree canopy and woodland cover by 0.33% of land area by 2030 from the 2022 baseline of 14.9% (net increase of 43,000 hectares) and to ensure 50% of SSSI features have actions on track to achieve favourable condition by 2030, and halt the decline in species abundance by 2030.

climate scenarios. These data show higher costs post 2030 for climate actions to maintain biodiversity targets, especially for high warming scenarios.

Based on this updated analysis, the additional costs to meet the biodiversity targets in the period 2030 - 2042 are estimated **at £240 million/year for a low warming (central ambition) scenario and £390 million/year for a higher warming (higher ambition) scenario** for England. This includes terrestrial and coastal biodiversity, but not marine.

There are no equivalent data and analysis for the Devolved Administrations. It is possible to get some indication of possible costs from a simple area based scaling using the 30 by 30 targets and associated area. This would imply values for the UK could be 1.86 times higher than for England alone, due to the large land area of Scotland but also the areas of Wales and Northern Ireland (noting this does not take into account the level of existing protected land or condition¹³). This increases the values above from £240 million to £390 million (for England) to £440 million to £730 million/year for the UK post 2030. However, these numbers are indicative only, and further there are three important caveats, discussed below.

First, the original IA climate study (Watkiss et al., 2021) highlighted that more targeted adaptation actions would be needed, over and above the interventions in the biodiversity targets, to fully meet the 30 by 30 target. Meeting the target would probably require targeted interventions for the most climate-vulnerable species, habitats and protected sites. These actions include buffer zones, connectivity to enhance species migration (in response to climate change), refugia, and in some cases, potential translocation. This would involve higher costs than the more general conservation actions assumed in the Impact Assessment. There would also be a need for a more dynamic and adaptive management approach.

Second, these additional costs are conditional on the definitions and targets set by the Government for the 30 by 30 target. Different assumptions about what constitutes the target will significantly affect adaptation costs, for example, the targets on condition of protected areas or what counts towards the target outside these areas. These issues are documented by EAC (2023)¹⁴. These assumptions can increase the costs of meeting the biodiversity targets (NLA, 2025)¹⁵, and in turn the adaptation costs. For example, if more or earlier actions are needed to achieve the 30 by 30 target, and costs are higher, then there will be additional costs of making these actions climate-resilient.

Third, adaptation costs will increase significantly in the 2040s and 2050s, especially under high warming scenarios. Therefore the numbers here – which are focused on the 2030s - are likely to be significant underestimates of future periods. For high warming scenarios, much higher costs are very likely.

All of these points indicate that **the costs below are likely to be significant underestimates**, however, linking back to Figure 1, this assumes that the biodiversity targets are maintained. If costs rise significantly, it would of course be possible to lower costs by

¹³ The proportion of adaptation costs associated with creation of new sites was low, and thus the higher levels of protected areas in Scotland would not affect the values. The main costs are for adapting protected areas, and species targets. Note also that some of the creation targets are included in subsequent peatland and woodland sections.

¹⁴ As an example, the wildlife and countryside link, 2025 identifies much lower levels of current protection and condition that Government, which means much more extensive actions are needed to hit 30 by 30.

¹⁵ The NLA (2025) estimate that the costs of meeting the 30 by 30 target could be much higher than the government estimates, especially if the 30 by 30 target requires more habitat creation and restoration, as this has much higher costs.

lowering the target levels¹⁶. There is insufficient data to know what the optimal level of action might be, and many would argue that where irreversible ecosystem losses are involved, such an approach is not appropriate. However, it is noted that the original Defra IA had high BCRs for meeting the target, and these would indicate that costs would have to rise very significantly before they exceeded benefits.

Table 8 Indicative adaptation costs for biodiversity for the UK (£/year). Source authors.

Category	Current period	2030s	2040s	2050s
Lower central range				
Biodiversity England* -protected areas -species abundance -red list species -wildlife rich areas	£200 million to £300 million/year*	£240 million to £390 million/year#	Not quantified but will be higher than 2030s, potentially significantly so	Not quantified but will be higher than 2040s, potentially very significantly so under high warming scenarios
Biodiversity UK ** (scaled from above)	£370 million to £560 million/year**	£440 million to £730 million/year	As above	As above
Upper estimate		Not quantified	Not quantified	Not quantified

*Modelling supporting Defra biodiversity target impact assessment and assessing additional adaptation costs on top of biodiversity targets, updated to £2024. Assumes targets for 2030 and then the 25YEP IA values. Note that higher targets than in the Defra IA would mean higher adaptation costs. This includes terrestrial and coastal biodiversity, but not marine.

**Values above scaled to UK level based on area targets for 30by30. Does not consider condition. Same scaling factors are assumed post 2030.

#based on IA modelling study and increase in costs in later decades from original analysis. The range reflects different ambition levels for the 25 YEP and different climate scenarios.

It is noted that many of the actions associated with these targets overlap with the actions below, including the Environment Land Management Schemes, and so the costs of actions in later sections are not added again, to avoid double counting.

Peatlands

Peatlands are a distinctive ecosystem. They represent a significant carbon store and play a role in climate regulation, but also contribute to wider ecosystem services, both onsite and offsite. There are lowland and upland peatlands, as well as bogs, but unfortunately, many are in a damaged state (drained or eroded) due to land management and pollution. As a consequence there have been targets set for restoration, though these are primarily undertaken to address the risks to carbon stores and enhance biodiversity.

The 25YEP and EIP set out targets for peatland restoration, which were included in NAP3. These were that Defra would restore 35,000 hectares of peat by 2025 and 280,000 hectares by 2050 in England, on the basis that this *stores carbon securely, reduces greenhouse gas emissions, increases biodiversity and reduces the risk of climate hazards such as drought and wildfire*. The EIP2025 updated these targets, with a target to restore 40,000 hectares of peat by 2030, though the same long-term target of 280,000 hectares. It is noted that other peatland strategies (e.g. IUCN) identify much larger areas of vulnerable peatland, which would imply much greater areas of peatland restoration needs. The Scottish Government

¹⁶ For example, the assumptions about what should be counted for species abundance, and whether potential positive effects for generalist species are offset against negative impacts for more specialised species or those in vulnerable areas (e.g., montane areas, above the natural tree line), does make a large difference to costs.

announced an increase in investment in peatland restoration of more than £250 million over 10 years to support the restoration of 250,000 hectares of degraded peat by 2030, and aiming to restore more than 400,000 hectares by 2040 (SG, 2025). For Wales, there was a restoration of 3,000 hectares by 2025 (already met). There is a target in the national peatland programme that there will be capacity to restore 1,800 hectares of peatland every year and keep delivering at that scale (NR Wales, 2025). The Northern Ireland peatland strategy (DAERA, 2025) does not have a stated ha target as yet.

The CCC in the 7th Carbon Budget Balanced Pathway (CCC, 2025) assessed that the proportion of UK peatlands in natural or rewetted conditions would need to rise, with *annual rewetting rates reaching 45,000 hectares between 2030 and 2050*.

There is relatively good information on the costs and benefits of peatland restoration, which includes valuation of environmental benefits (Vivid Economics, 2020; Cambridge Econometrics, 2020). In theory, the additional costs of adaptation could be part of an extended analysis of such studies, looking at the future economic costs of climate change on peatlands, then assessing the costs and benefits of additional action. However, there is insufficient quantitative information to be able to assess these incremental climate risks. Climate risks to peatlands vary strongly with condition ecosystems (see Moxey et al., 2021), though the greatest risks are associated with degraded peatlands. Degradation risks and rates are likely to increase with climate change, and sites that are damaged are likely to suffer accelerated degradation. In extreme cases, degradation becomes irreversible. Furthermore, while restoration reduces climate risks to peatland, and can be seen as a form of adaptation, it is not clear how effective it is. Restoration reduces climate risks but it may not reduce risks completely (note wildfires are discussed separately below) and may only halt further degradation, not reverse it. This means it is possible that faced with climate change, especially for high warming pathways, restoration may need to be implemented earlier, and at greater scale, to avoid irreversible impacts (see Watkiss and Moxey, 2019) though there is insufficient information to know the level of increased scale or speed needed.

In the absence of information, an indicative analysis has been undertaken here. This takes the restoration programmes set out, and attributes a proportion of these costs to adaptation, following Figure 2 for the a intervention (where adaptation is one of a number of objectives). A proportion of restoration costs can be assigned as climate adaptation relevant, as a proxy for the additional costs of adaptation.

Restoration typically requires removal of damaging pressures, but also often remedial structural action, and involves high up-front costs. Management practices also need to change in order to encourage recovery. Earlier literature estimates of the up-front costs of restoration include a practitioner's rule-of-thumb figure of £1000/ha for average upfront costs (Moxey et al., 2021). Values range significantly with site type, for example Vivid Economics (2020) report costs (£2019) of £1,030 for upland, £1,910 for lowland and £4,420 for converting woodland to bog¹⁷. Costs also vary with level of degradation and site context, and there are large ranges. Recent analysis of peatland restoration costs from current restoration funding in Scotland (Glenk et al., 2025) reports an average cost of £1,550/ha (2020 prices) though the report cautioned against using average costs given the wide variation (the 5th percentile was £191/ha, while the unit cost at the 95th percentile was £4,483/ha).

There are also an additional set of operational costs, which are low (e.g., Vivid Economics cite a central value of £100/year). However, there can be opportunity costs (the price of

¹⁷ These are present value costs, and relate to upfront cost. They exclude the financing costs, including the cost of borrowing.

excluding or limiting previous activities taking place on the habitat). These are important for lowland systems where agricultural land is restored (removing previous use and removing production), or upland systems for land with profitable prior use for livestock grazing and grouse management. Vivid Economics cite a central value of £2,936 ha for these opportunity costs, but note this is a present value lifetime cost.

For this analysis we have used the restoration costs of from Vivid Economics/Cambridge Econometrics above and updated to current prices. We have also assumed – in line with the CCC 7th Carbon Budget and Balanced Pathway that by 2050, 20% of the peatland area restored is lowland and 80% is upland and weighted restoration in line. In current prices, this leads to an average value which is very similar to the central value from Glenk et al., 2025.

The next issue is what proportion of these total restoration costs should be attributed to adaptation. One way to do this would be to allocate costs in relation to the benefits of peatland restoration. These economic benefits have been estimated (Vivid Economics, 2020; Cambridge Econometrics, 2020), finding these are dominated by carbon and by recreation: the amount that restored peatlands generate in off-site adaptation benefits (e.g., downstream flood reduction) are very low by comparison. This would lead to a very low attribution level. However, this does not capture the adaptation benefit to the on-site peatland. An alternative attribution method is to base on the objectives and intent. The NAP3 does include climate resilience as an objective of peatland restoration, alongside three other objectives. On this basis we assign 25% of the restoration costs to adaptation.

The resulting values are shown in the table. These values can only be considered highly indicative. For the central value, we use the CCC balanced pathway figure – noting this is higher than government targets. Note that this does not involve double counting with the biodiversity targets above, as the earlier analysis excluded peatland restoration costs as an adaptation cost. These costs would increase when considered from the private perspective, because of the inclusion of financing costs and very importantly opportunity costs. The inclusion of the latter – assuming that the unrestored peatland had profitable prior use - would increase the present value cost by three times.

Table 9 Indicative peatland restoration costs and attribution to adaptation (£/year). Source Authors.

Category	Targets	Annual cost restoration (£million)#	Annual adaptation cost (£million)*
Current Government Targets			
England	40,000 ha by 2030	7.3	1.8
	240,000 from 2030 to 2050	17.5	4.4
	Total 280,000 ha by 2050	14.6	3.6
Scotland	250,000 ha by 2030	45.5	11.4
	150,000 from 2030 to 2040	21.8	5.5
	Total 400,000 by 2040	32.4	8.1
Wales	1,800 ha per year	2.6	0.7
Total GB	Post 2030 only		10.5
CCC UK	Balanced pathway. 45,000 hectares /year between 2030 and 2050 assuming 20% lowland 80% upland	65.5	16.4
	Upland		13.1
	Lowland		3.3

* Excludes wildfire risk. These are discussed separately below.

central value based on restoration costs from Vivid Economics (2019) updated to current prices. Note values do not include the financing cost of restoration or the opportunity cost of changing land management. Values presented as annual cost and not discounted to present values.

*assuming 25% of the costs of restoration should be attributed to adaptation. Central value shown.

Finally, we stress that peatland restoration might need to be brought forward, and/or the scale of the programme increased, due to climate change. These would lead to higher costs.

Woodlands

Woodlands, including commercial forests, is a sector with long lifetimes, and thus at potentially high risk from climate change. However, the potential impacts of climate change are extremely complex: forest growth may be positively impacted by some climate effects but negatively impacted by others, with the latter including changes in water availability, extremes (droughts, wind storms) and pests and diseases. Additional impacts can arise from changes in forest ecosystem health, and from increasing forest fires, affecting managed and natural forests. As above, the additional costs (and benefits) of adaptation should be the incremental cost of addressing these climate related increases. In practice there is insufficient information to assess these risks, and as with peatlands, it is difficult to creation, restoration and management actions and attribute to adaptation.

Some of supporting adaptation actions to scale-up climate-resilience were identified in NAP3, which states that Defra and the Forestry Commission will ensure new woodlands have current and future climate conditions considered in their design and species choice. NAP3 identified the £15.6 million Future of UK Treescapes Programme, though only 1/3rd of the programme looks potentially adaptation relevant. NAP3 also included the £17 million Nature for Climate Fund Sector Capacity Project to enhance quality, quantity and diversity of tree planting stock, and which is likely to be highly relevant. It also identified the £22.1 million funding to support high quality woodland creation and public good delivery through the Nature for Climate Research and Development programme, though this also does not look to be explicitly adaptation. There are relevant activities being undertaken by the Forestry Commission (the main forestry ALB) as documented in the ARP4 report (FC, 2024), though costs of adaptation are not reported, and there is a planned Climate Change Adaptation Strategy. There are also relevant activities undertaken by Forest Research, which is the principal organisation for forestry and tree-related research and receives government funding. Looking at these current public actions, which include research, awareness campaigns, training, information, etc., these imply annual costs of very approximately £10 million to £20 million/year for public enabling actions.

NAP3 also reported the published commitments for increasing woodland and canopy cover, which are primarily for biodiversity and carbon sequestration benefits. It reports that Defra and the Forestry Commission (FC) will seek to treble tree planting rates on a path to achieve the new statutory target of increasing tree canopy and woodland cover from 14.5% to 16.5% by 2050 (note this includes tree canopy cover provided by non-woodland trees). It set out that these new woodlands will *store carbon securely, reduce greenhouse gas emissions, increase biodiversity and reduce the risk of climate hazards such as drought, flooding and windblow*. The EIP2025 sets the commitment to increase England's tree canopy and woodland cover by 0.33% of land area by December 2030 from the 2022 baseline of 14.9% (equivalent to a net increase of 43,000 hectares). Scotland has a target to increase woodland cover to 21% by 2030 and Northern Ireland has tree planting targets for 2030. NAP3 highlights the woodland creation targets, but is also set a general objective to maintain

average forestry productivity (as a minimum) at current levels to 2080. These can be used to assess tree planting rates¹⁸.

There are also targets in the CCC 7th Carbon Budget (CCC, 2025). The Balanced Pathway targets outlines the sets out that the Balanced Pathway *sees more than 16% of the UK covered in woodland, an increase from 13% today, as new diverse woodlands deliver carbon sequestration in vegetation and soils. It is vital that tree planting rates more than double to 37,000 hectares per year, by 2030*. The report also (p191) also sets out that these rates need to increase to 56,000 ha per year by 2035 and the 60,000 ha by 2040.

There are different ways to look at the attribution of adaptation costs for these woodland creation investments. New woodlands generate some offsite adaptation benefits, e.g., improved water management, and thus there is a question of whether some of the costs of these investments should be attributed as adaptation costs (as with peatland above). However, these woodland targets are primarily delivering the biodiversity targets and also carbon sequestration objectives, and while they have some adaptation co-benefits, they would be low (in monetary terms). There is some analysis that indicates that adaptation benefits might be approximately 5% of the total benefit stream. This % value has been used for attribution.

The current England Woodland Creation Offer grant offers £10,200 per hectare¹⁹, though higher payments are available if it contributes to local community, nature recovery or the environment. There are also reviews of woodland establishment costs (see Thurin, 2024), which indicate costs might actually be higher (at least for some activities) in practice, and that they vary strongly with area. For this analysis, we have used values from the CCC (CCC, 2025). These include establishment costs for broadleaved woodland, and for coniferous woodland, and assume the woodland creation mix by 2050 to be broadleaf (65%) and conifer (35%).

However, these new woodlands also need to take account of future climate change to ensure they are climate resilient, e.g., the choice of trees in unmanaged woodland through to commercial forests are suitable for the future climate, and that other hazards such as wildfire risks, are managed. These involves some incremental costs (compared to the counterfactual without climate change). These are considered relevant and are included in addition to the attribution costs. This also includes the extension to consider wildfire risk, and managing pests and invasives, but these are discussed separately below.

The incremental costs of climate proofing new woodland is more difficult to estimate. There is a UK Forestry Standard Practice Guide on Adapting forest and woodland management to the changing climate (FC, 2022). This sets out the types of activities possible, though does not include information on the additional costs. These actions are relevant for tree planting, and the consideration of suitability (ESC analysis) for species is a condition of some grants²⁰. For commercial forests there are additional private costs, which can arise from changes in species choice and profitability, but also management practices, affecting operating costs, but also potentially financial returns. At a minimum level, there will be a cost to apply the guidance and undertake a climate risk assessment when designing new woodland or species

¹⁸ The initial English trees action plan strategy (2021) anticipated planting of 30,000 ha per year, but short term targets committed to 7,500 hectares/year by 2025. The more recent target in the EIP2025 only commits to 43,000 ha by 2030 (relative to 2022). Post 2030, Defra originally anticipated 10,000 ha per year to hit the 2050 target (NAO, 2023). The Scottish short-term targets imply higher planting levels, of 18,000 hectares per year currently, as part of the plan towards 2030, but there is no long-term target.

¹⁹ <https://www.gov.uk/guidance/england-woodland-creation-offer>

²⁰ Ecological Site Classification decision support system (ESC) use is required for English Woodland Creation Officer (EWCO) and Countryside Stewardship (CS) woodland creation grant applications. See FC, 2024.

(e.g., ESC analysis). Unit costs for this have been taken from Watkiss et al. 2025. This unit cost can be multiplied up by the new tree planting targets (based on CCC above), though the cost will vary with the size and nature of the new woodland site. It is stressed that the actual cost of the actions identified in the climate risk assessment are not included. The costs of these will depend on the type of woodland, and could be high for commercial forests if these involve changes in species, density or even management practices. As a sensitivity, a simple adaptation mark-up has been applied, similar to that used for the transport analysis above, and applied to future woodland investment levels. These approaches indicate modest costs.

A more challenging issue is tackling the existing woodland stock. This is a much bigger task as the existing stock of woodlands and forests is estimated at 3.29 Million Ha in the UK (Forest Research, 2025). From the public side, this is likely to require a more ambitious extension, with a higher level of awareness raising, research and monitoring, and upskilling activities. For land owners, there will be a variety of costs associated with risk analysis and contingency planning, changes in management practices, etc., as well as potential costs along value chains (e.g.. processing sector). There is no information to allow even an indicative analysis of these costs, though note wildfire management is considered later.

The costs are summarised below, though the confidence in these estimates is very low and there are many gaps. It is stressed that these values are associated with the CCC Balanced Pathway and the level of tree planting recommended. As set out above, this is much higher than current Government targets. The use of the latter would lead to lower adaptation costs, because of lower tree planting rates.

Table 10 Indicative adaptation costs for woodlands*(£/year) assuming CCC balanced pathway. Source Authors.

Category	Actions	Indicative Costs
Public enabling actions for woodland	Research Guidance and awareness raising Surveillance and monitoring Sector capacity building (nurseries, forest managers, NGOs, etc.).	Plausibly £10 – 20 million/year based on current NAP3 costs
Climate resilience in <u>new</u> tree planting# (CCC scenario)	Application of guidance (climate risk assessment, suitability analysis) and low regret actions based on adaptation mark-up for CCC tree planting targets	£26 million/year
Attribution of adaptation to new woodland creation ** (CCC scenario)	Based on current establishment costs and attribution to adaptation benefit streams based on CCC tree planting targets and woodland mix	£24 million/year
<u>Current</u> woodland and forests	Adaptation actions for existing woodland and forests	Not quantified
TOTAL		Not quantified

* Excludes wildfire risk and pest, diseases and invasives. These are discussed separately below.
 ** Costs based on planting costs from CCC. Assumes CCC balanced pathway planting rates. Assume a 5% attribution to adaptation.
 # Excludes costs of major changes in management practice, and changes in profitability from species change or management.
 Note that these adaptation costs would be lower for current Government targets, as these have lower planting rates than the CCC pathway. See discussion of targets above.

A further issue for woodland and forestry is the issue of pests and diseases, including invasives. This has been a major issue in other countries, with notably outbreaks of pests and diseases in Canada and Europe, which have led to very high losses. This can arise from

the greater range or intensity of outbreaks of indigenous pests and diseases, but also the risks of invasive non-native species (INNS): these are addressed in the relevant risk analysis below.

Wildfires

Wildfires are uncontrolled vegetation fires. They can be ignited by natural sources, such as lightning, but most ignitions are related to human activities (e.g. agriculture, campfires, arson). Wildfires are exacerbated by the availability of combustible fuels and land-use management, but also by weather conditions. The main weather drivers include relative humidity, precipitation, wind, and temperature and compounding factors of low rainfall periods and drought (soil moisture).

Wildfire size and severity are generally considered to be increasing, and there are indications of an earlier start to the wildfire season. Wildfire statistics are published for England by the Forestry Commission (FC, 2022) and these report an average of over 30,000 incidents per year leading to, on average, a total burnt area of 6,600 hectares per annum, but with higher impacts in extreme years (e.g., 26,000 hectares in 2018-19²¹). Wildfire statistics are not collated in the same way for DAs, but there is wildfire prevalence data for Scotland (JHI (2022)). The Home Office (2023) assessed the economic and social costs of fires, including wildfires, estimating the total aggregate marginal costs for wildfires at £90 million/year on average (though this is likely to underestimate the full economic costs, including non-market impacts).

UK wildfire incidence and impacts are low by European standards, and while the conditions for the risk of wildfires are projected to increase under climate change (Arnell et al., 2021; Perry et al., 2021), the likely increase is modest, estimated at potentially a doubling by mid-century. However, there will be greater risks in extreme years. There is a growing focus on prevention and there are established practices from other countries with greater levels of wildfire risk today.

Wildfire mitigation actions are generally categorised into suppression (response) and prevention (anticipation). Most current action focuses on suppression, i.e., controlling wildfires once established and reported, though there is a growing need for prevention. There have been reviews of potential wildfire reduction measures (adaptation measures) for England and the UK (Glaves et al, 2020; Costa et al., 2020 Belcher et. al. 2021). These identify a range of measures, which can be simplified to:

Suppression

- Enhanced training and resources tackling wildfires;
- Enhanced site actions, e.g., enhanced vehicle access, water sources on moors;
- Targeted suppression measures, e.g., peatland-specific fire-retardants.
- New equipment (e.g., aircraft);

Prevention

- Information and awareness raising campaigns, for land managers and the public;
- Improved monitoring and modelling of wildfire risk, including early warning;
- Improving interoperability between land managers and FRS);
- Wildfire risk management (plans);
- Training and rural campaigns for prescribed burning/suppression;
- Preventative action on or around sites, e.g., reduction of fuel load e.g., use/removal of biomass;

²¹ Note these statistics do not include the hot summer of 2022.

- Reduction in fuel or fire continuity, including fire breaks, fire management planning in landscape planning, mosaics of diverse land uses (i.e., from site to landscape level).

Internationally, many of these options have been implemented, but there is not good data on the cost-effectiveness of actions, and risks, and thus benefits and costs, are highly site and context specific. A detailed review (Watkiss and Moxey, 2021) found limited economic evidence, though some low regret activities are summarised below.

NAP3 did identify some existing prevention actions, including the existing Met Office Detailed Fire Severity Index (FSI) (Met Office, 2025). The costs of this system are considered to be modest. However, there are additional actions that could seek to reduce ignition sources by changing the behaviour of people (as human activity causes most wildfires) through processes of awareness-raising, education, and/or exclusion. Pilots in the UK (Peattie et al., 2012) did that proactive and reactive education measures could reduce the incidence of wildfire arson, reporting a benefit to cost ratio of 1.7:1 just for avoided fire service costs. It is difficult to estimate exactly how much these public actions would cost. It is possible to look at the costs of typical awareness raising programmes, for example, with previous Home Office campaigns. These indicate costs per campaign of up to ~£1m.

NAP3 also set out support (guidance) on wildfire risk to forestry, woodland and peatland managers, and upskilling land managers, as well as research, along with a (nonspecific) action to upskill the public. It also made a commitment for a Wildfire Strategy and Action Plan, but this does not seem to be published at the time of writing. Defra did investigate a training package for upskilling land managers for land management burning (controlled burns) (Watkiss and Moxey, 2021). The estimated cost of this training was £1.5 to £7 million, though this was small-scale programme. If similar programmes were extended, as implied in NAP3, to forestry, woodland and peatland managers then would be a scale up of these costs. An indicative costs of £20 million (total) is plausible, but this would be a one off cost. This programme was estimated to deliver a BCR of 1.5:1 (Watkiss and Moxey, 2021).

A further option that can be considered is more targeted weather and climate services for wildfire, beyond the existing FSI. There are services in other countries which report cost-effective reductions, but these tend to have higher baseline wildfire risks. To be effective these also require activities from foundational activities including science and observations, forecasting capacity and accuracy, effective communication, and the uptake and use of this information by end-users. Nonetheless, this would seem a likely low regret action.

While indicative, we identify that early public actions to scale up wildfire early warning, awareness and training might have a cost of approximately £10 million/year post 2030.

The main focus of wildfire adaptation –related to the largest economic costs - are on peatland and woodlands. Peatland is very vulnerable to ignition during periods of drought and peatland wildfires are extremely difficult to control and to suppress, as wildfires can travel quickly, and can even spread underground. Peatland is the largest source of very large wildfires²² (Forestry Commission, 2022) and can release very large quantities of carbon and air pollution, and thus have very high economic costs per wildfire (see Watkiss and Moxey, 2021 for Defra). The main focus to address these currently are Wildfire Management Plans which have various components including Wildfire Risk Assessment (WRA), Wildfire

²² The Saddleworth moor wildfire burned for three weeks in 2018, covering 8 km² (800 ha) (Graham et al., 2021) and was estimated to have emission rates of CO₂ similar to a medium sized power station (as reported in CCRA3, Berry and Brown, 2021). An even larger wildfire occurred in the Flow Country (Scotland), over a large area of blanket bog peatlands, with a wildfire that covered 5,500 hectares in May 2019 (JRC, 2019) and which released an estimated 174,000 tonnes of CO₂. (HNM. 2019).

Management Zones (WMZ), Wildfire Prevention Measures (WPM) and Wildfire Response Plans (WRP). NAP3 announced a target of developing wildfire management plans for 20,000 hectares of habitat by 2025, a target to increase the number of woodlands within high-risk areas that have wildfire management plans (WMP) by 2030.

There is already well established with guidance from the forestry commission on wildfire risk management plans (Forestry Commission, 2014). The costs of meeting the target for 20,000 ha of WRMP (see NAP3) has been investigated (Watkiss and Moxey, 2021). Based on interviews, this found that the costs of these plans are relatively modest, though increase for larger sites and for more complex analysis. The analysis estimated a plausible cost of £6.2 million, though with an upper estimate that could reach £11 million if this was applied to lots of small sites of a few hectares each.

The costs of meeting the additional NAP3 2030 goal (to increase the number of woodlands within high-risk areas that have wildfire management plans by 2030) depends very strongly on the definition of high risk, and thus area covered. There is information on wildfire statistics which could support a definition of high risk, though it is stressed that the number of high-risk areas will increase with climate change, potentially doubling by mid-century (noting risk is a factor of human influence as well).

The cost of making all woodland creation schemes (see woodland above) include comprehensive wildfire management plans would seem a sensible early action for a well-adapted UK. Using the unit cost from Watkiss and Moxey (2021), and the area targets from CCC 7th carbon budget discussed above (CCC, 2025), this is estimated at £17 million/year post 2030 (noting as above, the cost depends on the size of new woodlands).

We assume that some simple low regret actions, including contingency planning, would be included within these plans. However, the costs of implementing these plans can have much larger costs to woodland managers (public or private). Some of these might be modest (e.g., firebreaks) but others (e.g., managing fuel load, changing spacing, increased diversity) could have very large costs (either because of the labour required or because of the effects on profitability for commercial forests). We have not estimated the costs of these actions, and there would be a need to consider whether these could be justified in cost-benefit terms, given the low probability of wildfire (and even in the future), e.g., a more cost-effective response might be to scale up insurance.

A broader issue is the level of wildfire risk for existing woodland and forests, noting as above this involves a far larger stock. It is unclear how much of existing woodland and forests have wildfire management plans already (noting guidance is in place). The current NAP3 action identifies an action to address high-risk areas, and the number of areas at high risk will further increase with climate change. If one assumes that 5% of forests in England are high risk, and that this number will double by 2050, then rolling out wildfire management plans to these over 20 years might have an annual costs of £5 million. Again, actually implementing these plans would have much higher costs. There could also be the extension of similar programmes to the DAs, noting that Scotland has a significantly larger area of woodland.

It would also be possible to require wildfire management plans for peatland restoration, however, restored peatlands have lower wildfire risk. Watkiss and Moxey (2021), based on relative IPCC emission factors for drained and undrained peatlands, indicate a five-fold reduction. The focus is therefore likely to be on existing drained and degraded peatlands. It is possible to use the current restoration targets to provide the number of at-risk peatlands in

2030, which for England and Scotland²³, would total almost 400,000 ha (see table above), and using the same approach, this would equate to £6 million/year from 2030 onwards.

Costs of extending wildfire management plans to other area types are not included, because often they cannot be justified on cost-benefit terms (see Watkiss and Moxey, 2021). This is because these areas have a low probability of fire occurrence, but also because they lead to lower burnt areas, and much lower economic costs than wildfires for peatlands or forestry.

Table 11 Indicative costs for wildfire adaptation (£/year). Source Authors.

Category	Actions	Possible Costs
Current NAP3 wildfire adaptation costs	Fire Severity Index	Not reported.
	Target to deliver 20,000 Ha of wildfire management plans by 2025	Not reported. Estimated at £6 million but depends on number of site
	Goal to increase number of woodlands within high-risk areas that have wildfire management plans by 2030	Costs might be similar to above, but depends on definition of high risk.
Future costs		
Public enabling actions	Improved early warning and climate services, awareness raising, training	Plausibly £10 million/year
Future wildfire adaptation costs for woodland and forest (CCC pathway)*	Assuming all <u>new</u> woodlands to have wildfire management plans, for CCC 7 th creation levels, 2030 - 2050	Estimated at £17 million/year in period 2030 - 2050
	Additional wildfire control measures in these plans (spacing, firebreaks, etc).	Not quantified.
	Wildfire management plans in 5% highest risks <u>current</u> woodland and forests in England	Estimated at £5 million/year in period 2030 - 2050
	Additional wildfire control measures in these plans (spacing, firebreaks, etc).	Not quantified
Future wildfire costs for peatland#	Assuming all <u>current</u> degraded / drained peatlands to have wildfire management plans and low regret actions	Estimated at £6.1 million/year in period 2030 - 2050
	Additional extensive wildfire control measures in these plans	Not quantified.
Additional adaptation actions for suppression	Capacity building, training, potential equipment (planes)etc	Not quantified
Sub-total		£38 million/year
Total		Not quantified

See text for notes and caveats.

* This assumes tree planting rates consistent with the CCC balanced pathway. This involves a higher level of tree planting than current Government targets. The use of Government targets would reduce these costs, because a lower number of new woodland would be created and thus there would be less climate proofing.

#This estimate depends on the assumed level of degraded peatlands. The values here are based on the CCC targets under the CCC balanced pathway. Different estimates of degraded peatland would alter these costs .

Farmland including Soils and Agriculture

There are a number of different types of adaptation actions for farmland. These include:

- Targeted adaptation public goods, for example, on site actions that have the primary objective of off-site climate risk reduction, such as nature based flood solutions.

²³ Note that large peatland wildfires occur, such as 5,500 hectare wildfire in the Flow Country in 2019.

- Actions that have adaptation as one of several objectives, or as a secondary objective (co-benefit). This includes a further set of actions but involves attribution, including:
 - Agro-environment schemes (agroecological) such as habitat creation or species-supporting habitats. These are covered in the biodiversity section above.
 - Agro-environment schemes that have on-site and off-site benefits, e.g., soil management, noting these have private and public good benefits.
- Adaptation to address the productivity losses associated with farming and food production, primarily involving private adaptation benefits and private costs, but supported by public enabling actions.

The first two are relevant as part of the shift from government farming (agricultural) subsidies away from production to payment for public goods (and positive externalities). The final one, the private adaptation to address productivity risks, is different, but due to market failures, there is a role for government to intervene with support and enabling actions.

There is data on current public spending. Spending on farming was set at £2.4 billion per year in England by the previous Government, and similar payment levels have continued, but have been increased to £2.7 billion to account for inflation (HMG, 2025). At the UK level, spending on farming is £4.4 billion (Defra, 2025c for the year 2024).

However, there has been a move away from production payments (subsidies) to payment for public goods, predominantly through the Environmental Land Management Schemes (ELMS) in England, and similar schemes at the UK level. In 2024, 51% of UK farming payments were associated with Agri-Environment Schemes (£1.2 billion), primarily though not limited to the Countryside Stewardship Scheme (CS), Environmental Stewardship Scheme (ES) the Sustainable Farming Incentive schemes (SFI) and Landscape Recovery schemes (LR) (Defra, 2025c). Going forward, the expectation is that ELMS and agri-environmental schemes will dominate payments.

It is more difficult to say exactly what level of adaptation is involved with this farming spend. The Agriculture Transition Plan and subsequent ELMS publications (Defra, 2023c: 2023d) identified long list of actions that schemes would pay for, and these include relevant targeted adaptation public goods, such as natural flood management (NFM), as well as AES with adaptation benefits, such as soil management. It also includes creation and species-supporting habitats include hedgerows, etc., which were included in the biodiversity section above. However, further work would be needed to analyse these current statistics in detail and identify the exact adaptation spending profiles. This would need an analysis of the relevant adaptation attribution (see Figure 2) for each individual action.

Targeted farmland adaptation actions

The initial focus is on targeted adaptation actions that have adaptation as a primary objective. This is mostly focused on water related actions. These are also options that are eligible for payment for public goods in ELMS.

The first set of actions relate to natural flood management (NFM). This has the potential to overlap with the CCC flood analysis, but discussion with CCC identifies these land options are additional. NAP3 set a target for Defra and the Environment Agency to double the number of government funded projects which include nature-based solutions (NBS) by 2027 to reduce flood and coastal erosion risk. There was also a £25 million fund for improving flood resilience through a new NFM programme²⁴ (capital programme) which built on the £15 million NFM Pilot Programme, which supported 60 projects between 2017 and 2021, and

²⁴ <https://www.gov.uk/guidance/natural-flood-management-programme>

there were also around 144 NFM projects in the £5.2bn flood and coastal defence programme. The NFM programme was announced in 2023. The target was announced as 260 NFM projects between 2021 and 2027.

In theory, the additional costs of NFM should be part of a broader analysis of the optimal balance of actions to address flood risks (e.g., the optimal balance of hard flood protection and upstream natural flood management). The Environment Agency Long Term Investment Strategy (LTIS) (EA, 2019) included a sensitivity that investigated this and concluded that a moderate amount of NFM combined with conventional FCERM investment gave the highest NPV for a given level of investment (though it did not report on the NFM cost levels in this scenario). More detailed analysis will emerge with LTIS2.

For the analysis here, we draw on previous work supporting the consideration of adaptation objectives for farming and countryside and ELMS (Watkiss et al., 2023), which looked at scenarios of natural flood management. This was based on a spatial targeted approach, to the highest flood risk catchments, i.e. priority catchments not nationally. These costs were assessed over the period 2025 to 2050, with the average investment level reported here. It is stressed that this analysis was based on a targeted approach, based on priority catchment area, rather than the economically optimal level. As the benefit to cost ratios were above 1 (noting this was the overall economic benefit, including environmental benefits), this implies a potentially higher level of NFM investment could be warranted. These numbers have not been scaled to the UK, but they would be higher if similar levels of NFM was assumed for high risk catchments. Again it is stressed that these numbers will be superseded by LTIS2.

A recent analysis by Sayers et al. (2025) looked at various levels of NFM ambition for Great Britain and looked at optimising the return on investment. The results indicate that NFM has the potential to contribute significantly to flood risk reduction in many catchments, and implies a higher level of investment, but it also finds that there are diminishing returns, reinforcing the message above around targeting and complementarity.

There are also a set of water management actions for farmland. There was a long-term Defra aim to increase water storage used by the agriculture and horticulture sectors by 66% by 2050 compared to 2024, and an unspecified commitment to provide £10m to look at barriers for on-farm storage in NAP3. There are also relevant actions included in ELMS. However, agricultural water management actions are already included in the CCC water system, which includes agriculture actions, and so costs are not included here to avoid double counting.

Soil management

Soil performs several important functions: it supports food production, water storage, biodiversity conservation and carbon storage, and thus provides provisioning, regulating and supporting ecosystem services. The ability of soil to perform these services is reduced when it is degraded (its quality is reduced) or eroded (its quantity is reduced), as can arise from several factors, including weather and climate change.

Climate change can potentially impact on soil quality through a number of pathways (Morison and Matthews, 2016):

- Soil degradation. This can include multiple processes, including those below;
- Soil erosion, notably from run-off, heavy precipitation and floods, and from wind;
- Soil compaction, arising from multiple factors, which can also increase run-off and flooding;
- Loss of soil organic carbon;

- Multiple climate factors affecting vegetation cover and soil processes, affecting function, water holding capacity, salinization, etc.

The most direct climate pathway is from soil erosion, which leads to the reduced productivity and reduced soil carbon (and increased GHG emissions) and can also lead to downstream impacts. These processes are complex and involve multiple factors, including the nature of the soil, slope and topography, vegetative cover, etc.

There are estimates of the economic costs of soil erosion, and analysis of the additional costs of climate change. Watkiss et al (2021) drawing on various studies, identifies the climate related economic costs of soil erosion at £160 million/year for the UK currently, and that this would rise two to three times higher with future climate change.²⁵

There are a set of sustainable soil and land management practices which can reduce the above impacts, and which have on-site benefits as well as off-site benefits. These can often generate positive externalities, such as carbon benefits, as well as tackling climate related impacts, which will have private benefits in terms of productivity (though over long periods). These often overlap with climate-smart agriculture options in the literature, which are defined as actions that have positive yield productivity benefits, reduce GHG emissions and enhance climate resilience. They include options such as agroforestry, cover crops, mulching, buffer strips, and others. Many of these options are already in ELMS.

NAP3 identified a number of options associated with soil management. These included soil monitoring schemes, but also a target to encourage landowners to sustainably manage at least 40% of England's agricultural soils by 2028 (with the rationale this will make them more resilient to the impacts of drought and flooding and better able to support food and biomass production). NAP3 also reported that Defra will pay for the establishment and maintenance of silvoarable and silvopastoral agroforestry systems (cropland and pastureland, respectively) in 2024. However, all these soil management options, while they deliver adaptation benefits, have multiple objectives not just climate change, and adaptation is often a co-benefit.

The CCC 7th Carbon Budget does include agroforestry, with the balanced pathway increasing the area of agricultural land converted to agroforestry to 47,000 hectares by 2030 and up to 200,000 ha by 2050 (8,000 hectares each year). Costs are available from previous CCC analysis (Vivid Economics, 2020) for establishment costs (present value) reported of £1,220 for silvoarable and £680 for silvopastoral agroforestry, but there are a much wider set of costs and benefits including revenues. As with the analysis above, it is possible to attribute some of this investment to adaptation. However, even attributing one third of establishment costs to adaptation, on the basis of the triple objectives of productivity, GHG abatement and climate-resilience, leads to low annual costs, at only a few £million/year (because the area established each year is relatively low).

Posthumus et al. (2015), using an ecosystem services valuation approach, found that many farm measures to reduce soil erosion did have positive net present values. The most cost-effective were tramline management, mulching, buffer strips, high-density planting and sediment traps, while agroforestry had a negative NPV (although this did not capture all ecosystem service benefits and used a lower value for carbon emissions). Moran et al (2013) analysed a range of measures for addressing soil (including drainage, and addressing soil compaction, as well as cover crops, shallow and contour ploughing) and found more and found that these generated positive NPVs (with one exception, for cover crops). The capital

²⁵ Note that the full costs of soil degradation are much higher, typically cited at £0.9bn to £1.4bn (e.g., Defra, 2023) but these include all pathways, not climate specific. This value is from a Graves et al study and from 2015, and significantly underestimates carbon values and is not in current prices.

costs of drainage used ranged from £1,750 to 2,500/ha (2012 prices), but it was the costs of cover crops that dominated the values (though these all depend on uptake rates, as well as assumptions about productivity changes and opportunity costs).

This does indicate that there could be an economic case for improved soil management to address rising climate related risks, and that when all benefits are taken into account, this is considerable stronger.

There is some data on the current uptake of the Sustainable Farming Incentive (Defra, 2025d). This highlights the growing uptake of soil management actions, especially SAM1 'Assess soil, test soil organic matter and produce a soil management plan'. This can receive annual payments of £6.00 per hectare (ha) and an additional payment of £97 per agreement. The UK agriculture industry was made up of 216,000 farm holdings and the utilised agricultural area was 17.2 million hectares of land, 71% of the UK land total (Defra, 2023). While it is overly simplistic, it is possible to multiply these numbers together, e.g., assuming every farm holding should have a soil management plan, and that this covers all hectares of agriculture land. Based on current payments and the current payment values above, this would equate to £124 million/year for the UK. However, not all of this should be attributed to adaptation. If allocated based on benefits streams, the most important benefits of soil management (in monetary terms) are reduced carbon emissions, which are much higher than productivity benefits, and other benefits (reduced run-off, sediment, etc). However, climate change will be a major driver of increased soil erosion, and it will be a higher relative factor in the intent of action in the future .

Further, a soil management plan is only as good as the actions it then leads to. There are additional costs for many of these actions, though some can be taken by management changes at very low cost, and others may generate net positive outcomes due to production benefits. As an example, in SFI, annual payments for multi-species winter cover crops are £129 per ha and for herbal lays are £382 per ha. As above, the literature on the net economic benefits of cover crops is mixed (See Moran et al., 2013).

This highlights that assessing the optimal level of action is very site and context specific, and requires detailed analysis, considering many factors including changes on production and prices. At the same time, the allocation of costs to adaptation should not exceed the economic costs of inaction (which as above, are plausibly around £160 million/year current and could double over the analysis period with climate change). Given the need to ensure economic and financial returns are sufficient, this might indicate plausible levels of £25 million to £100 million per year post 2030. This value is used here as an illustrative value, but clearly further work is needed to improve these estimates.

Adaptation to enhance productivity (private costs and benefits)

The areas above focus on the potential for land managers to support environmental or adaptation objectives, which have positive externalities and are thus can be linked to payment schemes. However, climate change will also have large effects on agricultural productivity, though these will be uneven, by system and across the UK.

Climate change can reduce productivity through changes in temperature, variable rainfall and more frequent extreme weather, but also create potential opportunities from yield benefits from CO₂ fertilisation or longer growing seasons. It will also lead to indirect effects, such as from changes in prevalence and outbreaks of pests and diseases. These combined effects will influence productivity, relative profitability, market prices, trade flows, and land-use decisions, with economic, social and environmental consequences. The boundaries drawn

also affect these effects, because other competing regions (e.g., Europe,) may be more detrimentally affected by climate change.

There is an extremely large literature on the potential impacts of climate change on agriculture in the UK, but this shows an extremely wide range of results, from large impacts through to net positive effects (noting there is large variation by production system and location). Further, different results are found when only a crop model is used, as compared to if the analysis is extended to economic models, including trade (see Watkiss et al., 2021), which again can often change the sign for the UK, due to more negative impacts elsewhere. Much of the recent literature on agriculture and climate change is more optimistic, especially as many studies now include CO₂ fertilisation, though this seems to contradict recent farming experience in UK and large weather related shocks in recent years, e.g., see CCRA4 (Bullock et al., forthcoming). It should also be stressed that crop modelling studies omit the full effects of extreme events, and exclude indirect effects such as pests and diseases (see Mansi et al., 2024).

There is also a broader issue on the objectives set for farm adaptation. This could be set to the economic optimal level (at least in theory, though this is very difficult to assess due to uncertainty) but it could alternatively be set based on other objectives, including food security, but also multi-functional objectives that include biodiversity, carbon, etc.

There are a set of adaptation actions to climate change that involve farm level actions, and primarily involve private costs and benefits. Much of the literature, especially that focused on crop modelling, tends to identify irrigation as the primary adaptation option (see Watkiss and Hunt, 2018). There are also other water management actions, such as on-farm storage reservoirs and incentivising efficient water management. These are relevant but irrigation and water management costs for agriculture and livestock are included in the CCC water sector analysis, so are not repeated here to avoid double counting.

However, there are a much broader set of adaptation options. These include low-regret options including agronomic options such as changing sowing dates, planting new cultivars or varieties, or changing management practices. These are often already happening as reactive or even planned measures by farmers as adjustments to weather and climate variability, however effectiveness is usually highly variable depending on the context for the measure, and differs for crops and regions. There are not good data on the costs of these, and they would be paid for by farmers. They are different to many of the actions supported by ELMS because they do not have public benefits/positive externalities (unless wider food security objectives are included). However, there are a range of barriers which prevent adaptation by land managers in the rural environment to climate change, especially from a societally optimal perspective. These barriers to adaptation lead to an insufficient level of adaptation, to maladaptation, or simply to inaction. These include information failures, as well as other market failures. There is a role for government to address these, and these actions are included in NAP3.

NAP3 states that Defra will provide free advice to help farmers to take adaptation actions for their businesses (p68) and cites the (Future) Farming Resilience Fund, though strictly speaking the fund provides business support to farmers and land managers for the broader agricultural transition and to ELMS²⁶. NAP3 also highlights the increase in the Farming Recovery Fund²⁷, but this addresses damages and is not considered as an adaptation action here. There are actions in the NAP3 for Defra to develop research outputs as part of their

²⁶ <https://ffrf.ricardo.com/mod/page/view.php?id=430>

²⁷ <https://www.gov.uk/government/news/farming-recovery-fund-expanded>

partnership with the Met Office Hadley Centre on climate resilient agri-food systems, which we assume includes climate services for agriculture²⁸.and to produce research reports (by 2025) to improve crop productivity, sustainability and resilience. NAP3 also sets out that Defra will begin offering capital grants in 2023 through the Animal Health and Welfare Pathway to fund health and welfare infrastructure projects and provide equipment to support good animal health and welfare in extreme weather events, though only a proportion of this is adaptation relevant. NAP3 also reported the Defra call for research and development projects to incentivise sustainable and resilient farming as part of the £270 million Farming Innovation Programme²⁹ spending over the Agricultural Transition to 2028/29. A review of the projects funded earlier in this programme (Watkiss et al., 2023) found these were not targeted at adaptation (though there are several projects on low carbon). A funding level of £63 million was set out in the Defra budget for the programme in 2025-26 annual accounts, and announced at £70 million³⁰, and this includes resilience, though again, only a proportion of the total programme is adaptation relevant. There are similar programmes in the DAs, but these have not been reviewed. There are also a number of commitment to breeding research, which NAP3 suggest have the potential to deliver crop varieties and livestock breeds with greater resilience to disease or climate change. This included £30 million investment in breeding research, though again this was not climate targeted. While not explicit in NAP3, there are climate services for agriculture, which include a public component³¹, though there are additional private tailored services as well. There are similar activities in the DAs, though these have not been reviewed.

It is difficult to exactly identify the exact spend of the range of current programmes, and even more challenging to attribute the relevant proportion that are really adaptation (e.g., where there is intent and objectives to address climate risks). The continuation of this public support to address market failures and create the enabling conditions for adaptation, including funding of research and pilots to enable private action at scale, will be needed post 2030. It is difficult to cost this with any accuracy, but plausibly it would need to be tens of £millions/year at the UK level as impacts rise. To provide an indicative value, we assume a continuation of current Farming Resilience Fund/ Farming Innovation Programme/Breeding research spending post 2030, but assume a greater proportion of this will be explicitly targeted towards adaptation and resilience, with an annual public spend of £45 million to 90 million/year for adaptation at the UK level. This represents only 1-2% of the current farming budget (see above). Further work is needed to investigate.

There will remaining private adaptation actions – noting that irrigation, climate smart agriculture and soil management activities are already included above – but there is not sufficient data to quantify these adaptation costs. Further work here is a priority.

There have been some European studies that have assessed the adaptation costs for agriculture, in France, Germany (Depoues and Dolques, 2024) and the EU (Neumann et al. 2026). The French analysis estimates around €1.5 billion annually may be needed over the next decade to deploy large-scale technical measures to maintain the yields of the main French crops, in a situation of increased climate variability. This includes a large number of practices and technologies, including the soil management and water management, but not including nature focused AES. The French agriculture sector is larger than the UK, but this would still imply large costs (hundreds of £million/year) for similar levels of action.

²⁸ <https://www.metoffice.gov.uk/services/government/food-farming-and-natural-environment-climate-service>

²⁹ <https://farminginnovation.ukri.org/>

³⁰ <https://defrafarming.blog.gov.uk/2026/02/24/nfu26-how-were-building-farming-resilience/>

³¹ <https://www.metoffice.gov.uk/services/government/food-farming-and-natural-environment-climate-service>

At the EU level, annual adaptation needs for EU agriculture were about €7.0–7.5 billion, roughly matching the €9.3–9.8 billion/year currently directed to agricultural adaptation and resilience (largely through CAP), but this includes all of the categories above, i.e., agri-environmental schemes as well as production.

Livestock, agriculture and aquaculture

For livestock, the focus has been on avoiding the direct effects on livestock from extreme temperature. There are potential impacts from heat stress from temperature extremes, which can in exceptional cases lead to mortality, but may more generally reduce productivity (Berry and Brown, 2021).

The Defra EIP has a target that by 2030, 58,000 Ha of agricultural land/water bodies will benefit from shading/cooling during extreme heat events. This provides a minimal level, though this is not the optimal level.

Previous analysis (Moran et al., 2013; Watkiss et al., 2023) have investigated potential cost of inaction and adaptation costs and benefits for livestock adaptation. Modelling studies are available on future projected financial losses to dairy cattle production from heat stress (Fodor et al. 2018). Estimated heat stress-related annual income loss for Southwest England (the most vulnerable region) by the end of this century was projected to reach £13.4 million in average years and £33.8 million in extreme years. This can be used to derive average losses per dairy farm and per ha. In order to estimate the adaptation benefits of increased shading to reduce these impacts, some assumptions have to be made on effectiveness. St-Pierre et al. (2003) indicates that alleviating heat stress could lead to a 29% reduction in heat related losses. This implies that by cooling 58,000 ha with increased vegetation, targeted at reducing heat stress in cows would have an annual cost of around £5 million, though based on addressing milk production losses, would have a positive BCR (5:1). It is stressed that this is not the optimal level, and it excludes risks to beef cattle, and thus should be considered a lower estimate.

There are also risks to other livestock, especially poultry, as well as other housed animals. CCRA4 highlights the impacts of the 2022 summer on poultry, including fatalities and production falls.

There is insufficient information to assess the potential adaptation costs for horticulture. We also note that aquaculture is not included here, though most of this would fall under the CCC system for marine.

Further work to consider all these adaptation costs is recommended.

Total farming costs

It is difficult to add up the total costs for farmland, because it includes actions that fall under many different categories, overlapping with biodiversity, flooding, soil management, water management (including irrigation) and both public and private actions.

Table 12 Indicative Adaptation Costs for Farmland (£/year). Source Authors.

Category	Current period	2030s	2040s	2050s
Land and agriculture nature including AES*	Detailed data not available and requires adaptation attribution	Included in biodiversity above	Not quantified	Not quantified
Upstream flood management – targeted to high risk areas and England only**		£115 million / year		Not quantified
Agriculture soil control (adaptation attributed)***		Illustrative £25 million to £100 million/year	Not quantified	Not quantified
Agricultural water management and irrigation#		Included in CCC water system		
Agricultural production public##		Illustrative £45 million to £90 million/year	Not quantified	Not quantified
Agricultural production private (additional to water, soil and nature)		Not quantified	Not quantified	Not quantified
Dairy #### lower estimate, EIP target only		£5 million based on EIP target	Not quantified	Not quantified
All livestock		Not quantified	Not quantified	Not quantified
Horticulture		Not quantified	Not quantified	Not quantified
Aquaculture		Not quantified	Not quantified	Not quantified

* The costs of habitat creation and habit supporting actions are already included in the biodiversity section, though most of these would be paid for through agri-environmental schemes to land managers.

** This value assumes spatial targeting to high risk areas only, and is only for England. The value will be superseded by more detailed analysis in LTIS2.

*** Illustrative figure, based on costs of inaction and possible actions.

The costs of water management actions for farmland including irrigation are included in the CCC water system and not included here.

Illustrative value based very approximately on current spending levels on farm support/innovation.

Based on EIP target for 2030 only. This does not reflect the level of costs of inaction or optimal adaptation response.

Freshwater

The consideration of water - in terms of supply and demand - are covered in the CCC Water system. The focus here is on the risks of climate change on freshwater, and the associated adaptation costs needed to address these. These involve a large number of climate risks, affecting water temperature, flows and quality, but these need to be seen against the background of other pressures and drivers, from agriculture, industry and wastewater. This means adaptation actions and costs are difficult to split out from wider water management.

This is reflected in NAP3, which focuses on good ecological status and good conditions, and includes a wider set of Integrated Water Resources Management (IWRM) actions including River Basin Management Plans, reductions in over abstraction, and actions via the Price Review process with water company. Many of these are included in the CCC water system, and thus not duplicated here.

There are some specific climate related risks, notably freshwater temperatures. NAP3 highlights actions to address these through the Defra 4-year Woodlands for Water Programme. There is also a target in the EIP that 58,000 Ha of agricultural land/water bodies

will benefit from shading/cooling during extreme heat events. There are some costs from previous studies on river quality improvements (Vardakoulias and Arnold, 2015) such as amplifying riverside vegetation. This generally involves planting additional trees or agro-forestry. The benefits arise from ecosystem service benefits, e.g., from reduced risk of higher temperatures on recreational fishing, amenity value, water abstraction, and other regulating and supporting services.

It has not been possible in this rapid study to assess these costs (and associated benefits), and they will be very site and context specific. The costs for the EIP target are likely to be modest, but a wider scale-up could be significant. Further work to investigate freshwater adaptation costs is recommended.

Pests, disease and invasives

The final area considered is the risks of climate change influencing the prevalence and range of pests, diseases, pathogens and invasive non-native species (INNS).

This risk potentially affects all of the land systems above, e.g., biodiversity, woodland, farming, freshwater, etc., and was captured in a large number of CCRA3 risks. Invasives already have economic costs of £billions/year in the UK (Eschen et al., 2023).

NAP3 set out an objective to reduce the number of new establishments of all invasive non-native species (INNS) in Great Britain by at least 50% by 2030 (compared to 2000 levels) and reduce impacts of INNS that are already established under a changing climate.

The main actions – in general terms – are for increased surveillance, early detection and monitoring mechanism, as well as horizon scanning, with prevention complemented with eradication and long-term management. NAP set out this would be delivered by the GB INNS Strategy, which was published in 2023 (Defra, 2023e), which sits along the Plant Biosecurity Strategy for Great Britain and the UK Biological Security Strategy (HMG, 2023).

There are multiple organisations involved in this landscape, and this makes it difficult to capture current spending. It includes Animal and Plant Health Agency (APHA) and Forestry Commission, as well as farm and ELMS payments, e.g., for Integrated Pest Management and biosecurity.

It has not been possible to estimate and attribution adaptation costs, but these are likely to be significant and further analysis is recommended

Overall assessment of adaptation costs for the land system

Given the lack of published information and studies, it is difficult assess future adaptation costs with confidence for the land system. The numbers from this rapid study indicate a central estimate of approximately £0.8 billion to £1.2 billion/year for the 2030s, but this omits a large number of important areas, and is therefore a sub-total of all adaptation costs. These costs are likely to rise in the 2040s and 2050s, potentially very significantly under high warming scenarios.

It is also noted that for a number of these interventions –the 30 by 30 targets, peatland restoration, woodland creation and soil management – the cost below only relates to the adaptation attributed fraction: the total costs of delivering these actions will be much higher, but they also deliver multiple benefits.

Further evidence is needed to gather robust cost estimates for future periods and for the overall land system.

Table 13 Indicative Adaptation Costs for the Land System (Cost£/year). Source authors.

Category	Current period	2030s	2040s	2050s	
Biodiversity UK central estimate* (note includes agri-environmental schemes)	Difficult to split out data and attribute to adaptation	£440 million to £730 million/year	Not quantified but will be higher, potentially very significantly if high warming		
Biodiversity Upper estimate		Not quantified	Not quantified	Not quantified	
Peatland restoration adaptation attribution UK**		£16 million/year		Not quantified	
Peatland adaptation high estimate UK**		Not quantified		Not quantified	
Woodland adaptation UK***new sites		£65 million year		Not quantified	
Woodland adaptation existing stock (central and high)		Not quantified	Not quantified	Not quantified	
Wildfire risk management plans and low regret for UK****		£38 million/year		Not quantified	
Wildfire adaptation actions at scale		Not quantified	Not quantified	Not quantified	
Land and agriculture nature and AES		Included in biodiversity	Not quantified	Not quantified	
Upstream flood management – targeted to high risk areas only (England only) #		£115 million / year		Not quantified	
Agriculture soil control###		Illustrative £25 to 100 million/year	Not quantified	Not quantified	
Agricultural irrigation and water management		Included in CCC water system			
Agricultural production public (indicative)####		Illustrative £45 million to 90 million/year	Not quantified	Not quantified	
Agricultural production private (additional to water, soil and nature)		Not quantified		Not quantified	
Dairy cattle based on EIP target#####		£5 million (minimum)	Not quantified	Not quantified	
All livestock		Not quantified	Not quantified	Not quantified	
Horticulture		Not quantified	Not quantified	Not quantified	
Aquaculture		Covered in marine system			
Freshwater		Some costs included in CCC water system, but direct impact risk not quantified		Not quantified	
Pests, diseases and invasives		Not quantified	Not quantified	Not quantified	
Sub total+		£749 million to £1159 million/year	Not quantified	Not quantified	
Total	Not known, see gaps above				

*See Table 8 for notes and caveats. Includes coastal and terrestrial but not marine.

**See Table 9 for notes and caveats. Assuming 25% of restoration costs are attributed to adaptation. See earlier table for notes and caveats. Note that for the high estimate, this would involve bringing forward and scaling up action, but this has not been assessed.

*** See Table 10 for notes and caveats. Assuming 5% of creation costs are attributed to adaptation and costs of climate-resilience in design of new woodland. Does not include additional management actions. See earlier table for notes and caveats.

**** See Table 11 for notes and caveats.

Assuming spatially targeted to high risk catchments only and England only. Note that wider application of NFM would have higher costs.

Illustrative figure, based on costs of inaction and possible actions. See text above and Table 12.

Indicative value based very approximately on current spending levels on farm support/innovation. See text above and Table 12.

Based on the EIP target only, not the level of impacts and needs. See text above and Table 12.

+ Note this is not reflective of the actual range, rather it is the sum of the numbers above, some of which have indicative ranges and some which do not.

Economic Benefits

There is some information on the economic benefits of many of the adaptation interventions above for land, and these indicate net positive economic returns, though this is due to the multiple benefits involved (not just risk reduction).

The benefit to cost ratio of delivering the 30 by 30 target was assessed in the Defra Impact Assessment (Defra, 2022a, 2022b) of the biodiversity targets, reporting a BCR of 6.2:1 in the low climate change scenario and is 3.1:1 in the high (but note, these are not the incremental costs and benefits of adaptation).

There are numerous studies on the economic benefits of peatland restoration, which indicate that restoration is generally worthwhile in most (but not all) cases, for both upland and even lowland peatlands, especially if a broader range of ecosystem services are included (Watkiss et al., 2021). Cambridge economics (2020) report a BCR of 4.6:1, but this is driven by carbon sequestration value.

Internationally there is good evidence that wildfire risk reduction is cost-beneficial in high risk countries, with international BCRs from 1.6:1 to 39:1 (World Bank, 2021). However, there is a question in transferring these values to the UK, because of the much lower wildfire incidence and damage, as compared to say Southern Europe. Watkiss et al (2023) indicates potentially positive BCRs for some types of habitats (e.g., a BCR of 1.6 to 2.4 for peatland WMPs and low regret actions) but below 1 for arable land and grassland, reflecting the low risks and also the lower economic costs when wildfires occur. This study also identified net positive economic benefits for targeted training campaign to land managers on controlled burning, and there some existing pilot studies in the UK indicate that educational measures could have positive BCRs above 1 (Peattie et al., 2012).

Soil management actions are generally reported to have positive economic returns for most but not all measures (Moran et al, 2013; Posthumus et al. 2015), though more recent carbon values would likely increase these to positive BCRs (but note they often had lower financial returns). Natural Flood Management can have positive BCRs, but it depends on location. Watkiss et al (2023) found spatially targeted measures could have positive BCRs, but non-targeted would not. Sayers et al. (2025) also found positive returns on investment at various levels of NFM ambition. Further analysis on returns will emerge with LTIS2.

For pests and invasives, enhanced monitoring and surveillance as well as early response, was estimated (Moran et al., 2013) to have high economic returns, with BCRs of up to 10:1.

In all cases, these economic returns are highly site and context specific. Positive economic returns are normally strongly influenced by multiple benefits, especially carbon.

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For more information, see www.lse.ac.uk/granthaminstitute/projects/attenuate



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