The economic value of the Met Office

Updated evaluation study of the economic value of the Met Office's activities to the UK over the next ten years

Final Report

LE
London Economics

August 2024

About London Economics

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Head Office: Somerset House, New Wing, Strand, London, WC2R 1LA, United Kingdom.

w: londoneconomics.co.uk e: info@londoneconomics.co.uk 𝕏: @LondonEconomics
t: +44 (0)20 3701 7700 f: +44 (0)20 3701 7701

Acknowledgements

We would like to acknowledge the useful guidance and feedback provided by the Met Office throughout this research. We would also like to thank all stakeholders that the project team had met with over the course of the project so far for the valuable advice and information they have provided. Responsibility for the contents of this report remains with London Economics.

Authors

Daniel Herr Associate Director
Tiffany Head Senior Economic Consultant
Clio von Petersdorff Senior Economic Consultant
Andrew Pritchard Economic Consultant
Moritz Profanter Economic Analyst
Charlotte Duke Partner
Moritz Godel Partner
Wouter Landzaat Senior Economic Consultant
Taras Wolczuk Intern
Phoebe Worsley Intern

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Glossary

Term	Description
AMDAR	Aircraft Meteorological Data Relay
ANSR	The Environment Agency's Non-Structural Responses tool
AV	Autonomous Vehicles
Baseline results	The central results for the headline 'Existing' Met Office scenario.
Baseline scenario	An alternative way to refer to the main scenario of the evaluation. In this case the baseline scenario refers to the 'Existing' Met Office scenario.
'Basic' Met Office	An alternative scenario under which the Met Office would only provide a more limited or 'basic' offering (see Box 3 in Section 3.2).
Benefits	The outputs, outcomes and impacts of the Met Office's activities
CAA	Civil Aviation Authority
CCRA	Climate Change Risk Assessment
Central assumptions	The main assumptions used in the analysis. These are the assumptions used to derive the central estimates
Central (benefit) estimates	The main, or central, results of the analysis. The term can refer to the central results for both the 'Existing' and 'Basic' Met Office and is used to distinguish the central estimates from the results of the sensitivity analysis.
Central case	An alternative way to refer to the main scenario of the evaluation. Used interchangeably with baseline scenario.
CNI	Critical National Infrastructure
COBRA	Cabinet Office Briefing Rooms
Counterfactual scenario	An alternative, often hypothetical, scenario against which benefits and costs are assessed. This study uses both a 'do-nothing' and a 'do-minimum' counterfactual scenario.
Confidence interval	A statistical concept measuring uncertainty around statistical estimates. It provides a range in which the true value is likely to lie.
'Existing' Met Office	The central scenario modelled in this study. It evaluates the total benefits and costs of the existing Met Office relative to a world in which there is no UK Met Office.
Defra	Department for Environment, Food and Rural Affairs
Downstream activities	Met Office activities that result in benefits users, referring specifically to the activity groupings used in this study (weather services, climate services, etc.)
'Do-minimum' scenario	An assumed counterfactual scenario in which the Met Office only provides a basic offering. This is equivalent to the 'Basic' Met Office scenario.
'Do-nothing' scenario	An assumed counterfactual scenario in which there is no UK Met Office. Reported benefits and costs of the 'Existing' and 'Basic' Met Office are assessed against this scenario. This enables assessment of total benefits and costs.
DESNZ	Department for Energy and Net Zero
DfT	Department for Transport
DSIT	Department for Science, Innovation and Technology
EA	Environment Agency
ESA	European Space Agency
EO	Earth Observation
ESO	National Grid ESO, the Electricity System Operator for Great Britain
ECMWF	European Centre for Medium Range Weather Forecasting
EUMETNET	A grouping of European National Meteorological Services
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
Enabling activities	Activities needed to enable Met Office downstream activities
FCDO	Foreign, Commonwealth and Development Office
FFC	Flood Forecasting Centre
FIM-IR	The Environment Agency's Flood Incident Management Investment Review
FWRBP	The Environment Agency's Flood Warning Response and Benefits Pathways model
GDP	Gross Domestic Product

GPS	Global Positioning System
GVA	Gross Value Added
Headline results	The central results for the headline 'Existing' Met Office scenario.
Headline scenario	An alternative way to refer to the main scenario of the evaluation. In this case the baseline scenario refers to the 'Existing' Met Office scenario.
HMG	His Majesty's Government
HMT	His Majesty's Treasury
HPC	High Performing Computing
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
Impacts	Met Office benefits referring specifically to more substantial and often medium-/long-term outcomes of the Met Office's activities.
Inputs	The resources needed for the Met Office's activities.
IPCC	Intergovernmental Panel on Climate Change
JMMP	Joint Marine Modelling Programme
LE	London Economics
MO	Met Office
MOHC	Met Office Hadley Centre
MOHCCP	Met Office Hadley Centre Climate Programme
MoD	Ministry of Defence
NAME	Numerical Atmospheric-dispersion Modelling Environment
NAP	National Adaptation Plan
National Capability	The key scientific and technological capability underlying the Met Office's climate and weather services
NERC	Natural Environment Research Council
NHP	Natural Hazards Partnership
NHS	National Health Service
NOAA	National Oceanic and Atmospheric Administration
NPC	Net Present Costs
NPV	Net Present Value
NRW	Natural Resources Wales
NWP	Numerical Weather Prediction
NSWWS	National Severe Weather Warning Service
Outcomes	Medium-term benefits/impacts of the Met Office's activities
Outputs	Direct outputs and short-term benefits of the Met Office's activities
PAGE	The Policy Analysis of Greenhouse Effects model
PWS	Public Weather Service
PWSCG	Public Weather Service Customer Group
PWMS	Public Weather Service Media Service
RNLI	Royal National Lifeboat Institution
RIMET	Radioactive Incident Monitoring Network
RREMS	Radiological Response and Emergency Management System
Sensitivity analysis	The sensitivity analysis analyses the impact on estimated benefits of uncertainty around all central assumptions used the modelling.
SEPA	Scottish Environment Protection Agency
ToC	Theory of Change
UKCP	UK Climate Projections
UKHSA	UK Health Security Agency
UKSA	UK Space Agency
UV	Ultraviolet
VAAC	Volcanic Ash Advisory Centres
WAFC	World Area Forecast Centre
WMO	World Meteorological Organisation

Source: London Economics

OVERVIEW OF THE REPORT

This report is structured as follows:

- **Executive Summary**.
- '**Report at a glance':** overview of the main findings and takeaways (infographic).
- The **main body** of the report is structured in three parts:
  - **Part** I introduces the study and the Met Office. By developing a Theory of Change for the Met Office, Part I highlights the Met Office's main activities (grouped into five key areas) and resulting outputs, outcomes and impacts.
  - **Part II** provides the updated economic valuation of the Met Office. In addition to aggregate benefits, Part II also provides an overview of the evaluation approaches, and whether individual benefits were monetised, for all key activities identified in Part I.
  - **Part III** explores key activities of the Met Office and their corresponding benefits in more depth. Part III has five distinct chapters, each examining one of the Met Office's key activity groupings highlighted in the Theory of Change.
- **Concluding remarks**.
- In addition, this report includes:
  - **Three annexes** providing further detail on the Theory of Change, the methodological approach, and the sensitivity analysis.
  - **Three case studies** highlighting the Met Office's contribution to Autonomous Vehicles, its tech partnerships, and UK Climate Projections.
- Throughout the report, case studies and additional information are shown in **blue boxes** to visually distinguish them from the main text. Technical discussions are presented in **grey boxes***. Evaluation results for benefit streams are presented in **green boxes.**

Note: (*) Where necessary to explain the key results. More technical details are provided in the Annex.
Image credit: Nik Ramzi Nik Hassan/unsplash

Executive Summary

Conclusions

The benefits of the Met Office's activities to the UK are substantial. The estimate of £18.8 of benefits accruing to the UK per £1 of public money invested in the Met Office from the central results is sizeable in comparison to similar estimates of other meteorological services across the world. Moreover, the study highlights the substantial additional benefits of having a 'world leading' Met Office over a more 'basic' meteorological service.

The study also highlights the substantial non-monetised benefits accruing both to the UK and globally as a result of the Met Office's activities. This, in combination with the assumptions used in the estimation methodology which caused estimates to be conservative, implies that the true value delivered by the Met Office is even larger than the estimated benefit-to-cost ratio.

Study objectives

This study provides an independent economic evaluation of the UK Met Office, updating the findings from the 2015 Met Office General Review (London Economics, 2015).

The main objective of the study was to evaluate the economic impacts associated with the Met Office's activities on the UK economy, society, and government between 2024 and 2033. The study focuses on consolidating and updating existing benefit valuations of the Met Office's activities, rather than introducing significantly new evaluation methods for previously unquantified benefits. It also projects previously estimated benefits forward for the period 2024-2033.

As such, the study should not be interpreted as a ground-up analysis of the Met Office's proposed or potential future activities.

Nevertheless, where gaps have been identified, these have been highlighted.

Benefits accruing outside the UK[1] and to the defence sector are outside the scope of this study.

Key scenarios

The study evaluated Met Office benefits and costs under two scenarios:

- An 'Existing' Met Office scenario which assessed the benefits and costs of the existing Met Office. Under this scenario benefits and costs were assessed relative to a 'do-nothing' counterfactual scenario under which there was no Met Office. This counterfactual scenario is defined to mean that Met Office meteorological services would not be provided and there would be no public investment in the Met Office. The scenario therefore estimates the total benefits of the existing Met Office. This scenario is also referred to as the 'baseline' or 'central' case.
- A 'do-minimum' counterfactual scenario under which the Met Office would only provide a minimal or 'basic' level of services (referred to as the 'Basic' Met Office scenario). Under

[1] The exception to this are benefits deriving from the Met Office's role as a World-Area-Forecast-Centre, which are international benefits. Therefore, some of these benefits inevitably accrue outside of the UK.

this scenario, the Met Office is assumed to focus on providing core meteorological services (i.e., provision of weather information and forecasts) and services to meet regulatory requirements (i.e., its UK aviation services). Services provided are also assumed to be of a lower quality. Comparison between the benefits and costs estimated under the 'Existing' and the 'Basic' Met Office provides insights on the additional benefits the Met Office provides over and above a more basic service provision.

Box 1 Modelled scenarios - explanation of key terms

To avoid confusion, terms referring to these various scenarios used throughout the report are briefly explained here:

- **'Existing' Met Office** – The central scenario modelled in this study. It evaluates the total benefits and costs of the existing Met Office relative to a world in which there is no UK Met Office.
- **'Basic' Met Office** – An alternative hypothetical scenario under which the Met Office only provides a more limited or 'basic' offering (see Box 3 in Section 3.2 for further details).
- **Baseline or headline scenario** – An alternative way to refer to the main scenario of the evaluation. In this case the baseline scenario refers to the 'Existing' Met Office scenario.
- **Central case** – An alternative way to refer to the main scenario of the evaluation. Used interchangeably with baseline scenario.
- **Counterfactual scenario** – An alternative, often hypothetical, scenario against which benefits and costs are assessed. This study uses both a 'do-nothing' and a 'do-minimum' counterfactual scenario.
- **'Do-nothing' scenario*** – An assumed counterfactual scenario in which there is no UK Met Office. Reported benefits and costs of the 'Existing' and 'Basic' Met Office are assessed against this scenario. This enables assessment of total benefits and costs.
- **'Do-minimum' scenario*** – An assumed counterfactual scenario in which the Met Office only provides a basic offering. This is equivalent to the 'Basic' Met Office scenario.
- **Central (benefit) estimates** – The main, or central, results of the analysis. The term can refer to the central results for both the 'Existing' and 'Basic' Met Office and is used to distinguish the central estimates from the results of the sensitivity analysis.
- **Baseline or headline results** – The central results for the headline 'Existing' Met Office scenario.
- **Central assumptions** – The main assumptions used in the analysis. These are the assumptions used to derive the central estimates.
- **Sensitivity analysis** – The sensitivity analysis analyses the impact on estimated benefits of uncertainty around all central assumptions used the modelling.

Note: (*) The study reports estimated benefits for both the 'Existing' and 'Basic' Met Office relative to the 'Do-nothing' scenario. This allows all benefits and costs to be assessed and makes interpretation of the figures clearer. To understand the baseline or 'Existing' Met Office scenario relative to the 'do-minimum' counterfactual, the results for the 'Existing' Met Office have to be subtracted from those for the 'Basic' Met Office.

Further details on the selected scenarios are provided in Section 3.2 and Annex A2.5.

Sensitivity analysis was undertaken to determine the sensitivity of the central headline results to changes in input assumptions.

Central benefit results

The total present benefits to the UK of the Met Office over the next decade (2024-2033) against the do-nothing baseline scenario (i.e. one where there is no publicly funded Met Office) are estimated to be in the region of £52.6bn using central benefit estimates (Table 1). This compares to a total present public investment into the Met Office, of around £2.8bn. **This implies benefits to the UK of £18.8 for every £1 of public money invested in the Met Office.**

Table 1 Met Office Benefits: Return on public investment

Metric		Central estimates	
		'Existing' Met Office	'Basic' Met Office
Total present benefits (excl. Met Office revenue)	*(b)*	£52.6bn	£22.4bn
Total present public investment	*(c)*	£2.8bn	£2.3bn
Total benefit per £ of public investment (public present benefit : public present cost ratio)	***(b/c)***	**18.8**	**9.9**
Net present benefit to the UK economy	***(b-c)***	**£49.8bn**	**£20.1bn**

Note: This analysis provides the estimated benefits, over the period 2024-2033, of the Met Office's activities to the UK economy relative to the amount of public funding received by the Met Office. The analysis of benefits to the public purse excludes Met Office revenues (i.e., Met Office commercial revenues and non-commercial revenue - such as public funding received by the Met Office) as i) commercial contract revenues are a transfer payment from UK businesses to the Met Office and so have a net-zero benefit to the UK taxpayer, and ii) non-commercial Met Office revenue is predominantly public funded and so, while it is a benefit to the Met Office, it is a cost to the UK taxpayer. In terms of costs this analysis only considers public investment into the Met Office (i.e., funds the Met Office receives from the UK Government or other public bodies). Actual operational costs of the Met Office are higher but, as a trading fund, the difference in costs is offset by revenues from the Met Office's commercial activities. The full breakdowns are provided in Section 4. Lastly, it should be noted that the return on public investment is calculated as a benefit-to-cost ratio (BCR) - i.e., public present benefits : present public investment. This measure is commonly used in Green Book analyses. However, it is not a return on investment in the sense used in financial analysis where net return factors in costs. Rather, it should be interpreted as a gross return with a BCR greater than 1 indicating that the benefits exceed the costs.

Source: London Economics

'Existing' vs. 'Basic' Met Office

The do-minimum scenario assumes a basic level of service. Under this scenario the Met Office would focus on providing core meteorological services (i.e., provision of weather information and forecasts) and services to meet regulatory requirements (i.e., its UK aviation services).

Due to the reduced services provided and the assumed lower quality, public benefits under this scenario are estimated to be substantially lower than under 'Current' service provision (£22.4bn vs. £52.6bn).

Key drivers of this reduction are:

- The closure of the Hadley Centre and associated loss of climate benefits – accounting for nearly two-fifths (38%, or £12.0bn) of the reduction in benefits.
- Loss of the Met Office's function as a World Area Forecast Centre and reduction in quality of remaining aviation services – accounting for 22% (£7.0bn) of the reduction in benefits.
- Reduction in quality of weather information provided to the public and industry – accounting for 13% of the reduction in benefits each (£4.2bn for the value to the public and £4.0bn for benefits to other business sectors).

While costs are also lower, under a 'Basic' service provision, the Met Office would no longer provide specialist consultancy and advisory services. Therefore, total costs under this scenario are assumed to be carried by the public purse. This means the total reduction in public investment needed is much smaller than the reduction in benefits (£2.3bn vs £2.8bn).

As a result, **the estimated benefit accruing to the UK in the 'Basic' Met Office scenario** is estimated at around **£9.9 per £1 of public investment**.

While this remains a good return on public investment, it is substantially lower than the £18.8 per £1 under 'Existing' service provision. This highlights the substantial additional benefits the existing Met Office brings to the UK compared to providing a more basic offering.

Further, the 'Basic' Met Office is a hypothetical scenario. It explores the impact of a hypothetical Met Office with a reduced service provision. In reality, the transition to such a basic service would be highly complex, would likely take several years, and incur additional costs (such as redundancy costs, transaction costs for moving to smaller premises, etc.), which are not modelled.

Crucially, the Met Office's new supercomputing contracts are already predetermined. A more basic service would not need the increased supercomputing capabilities (and thus the modelled hypothetical scenario assumes a lower supercomputing cost, see Annex A2.5). However, in reality the costs would still be incurred over the agreed time-horizon and the realised benefit-to-cost-ratio would therefore be substantially lower in the transition period.

Uncertainty surrounding central results

There is considerable uncertainty surrounding the magnitude of benefits that will be achieved over the next ten-year period. To assess the level of uncertainty, sensitivity analysis was conducted to examine the impact of changes in the central assumptions to the magnitude of total benefits[2].

The sensitivity analysis implies that **benefits could be substantially larger than the central estimate**. While benefits may also be smaller, the sensitivity analysis implies that this is less likely to be the case and that the potential downside to benefits is much more limited than the potential upside.

Moreover, in addition to the modelled uncertainties, there are likely substantial benefits which have not been quantitatively evaluated for this study and are therefore not captured in the sensitivity analysis (discussed further below). Therefore, the **central estimates presented in this study are likely to be on the conservative side.**

Uncertainty surrounding estimates **of climate benefits are a substantial driver of the uncertainty around estimated benefits**, accounting for more than half (55%) of the uncertainty in total benefits. This variation is driven by the complexity of estimating the magnitude of benefits of mitigation and adaptation measures to reduce the impact of climate change. As a result of this, underlying literature estimates of benefits vary widely (see Annex A2.1.3).

The remaining uncertainty is a composite of the much smaller uncertainty surrounding other large benefit streams including aviation benefits, benefits to industry and the public, and cold preventable deaths. Sensitivity results for individual benefit streams are provided in Annex 3.

[2] The results of the sensitivity analysis for central estimates are discussed in further detail in Section 5 in the main body of the report. Full results of the sensitivity analysis, including results for individual benefit streams and the 'Basic' Met Office counterfactual, are provided in Annex 3.

Both the range of potential benefits and the size of unquantified benefits can be assumed to be substantially smaller in the case of a more basic Met Office providing fewer and lower quality services (do-minimum scenario).

Benefit streams considered

The study considered the full range of Met Office activities and resulting benefits. To this end, a conceptual model (known as a Theory of Change) was developed. The Theory of Change captures all Met Office activities and benefits irrespective of whether they could be monetised or not.

The Theory of Change approach is a widely used framework to develop conceptual models in evaluation studies for central government. It is one of the best practice approaches to evaluation scoping outlined in the UK government's Magenta Book (HM Treasury, 2020).

Based on the activities identified for the Theory of Change, and the expected magnitude of impacts, Met Office activities were divided into five groupings:

- Weather services
- Climate services
- Benefits to industry
- Science, innovation and technology
- Other key activities

Activities and resulting benefits for each of these groupings are explored in-depth in Part III of this report.

However, as with any evaluation study, it was not possible to monetise benefits associated with all key Met Office activities. The table below provides an overview of the benefit streams that were monetised, and their respective contribution to the central baseline benefits presented earlier.

Table 2 Monetised benefits streams and their share of total 'Existing' Met Office benefits

Benefit stream	Description and approach	% share of total benefits
Aviation	Market-based estimates capturing the value of regulatory aviation services as a World Area Forecast Centre; and avoided cost approach estimating the value of efficiency improvements (e.g., fuel saving, better routes) from weather forecasts to aviation.	22.3%
Climate Adaptation	Based on a review of existing evidence undertaken for a separate study on the Met Office Hadley Centre Climate Programme (MOHCCP). The study identified literature evidence on the value of climate information to updating emission targets, supporting mitigation measures, and supporting adaptation.	21.4%
Value to the Public	Value of provision of weather information to the public based on willingness-to-pay survey of the public.	20.7%
Other Business Sectors	Value-chain-approach capturing the benefits of provision of weather information to industry sectors which are not already evaluated separately. The evaluation is based on weather sensitivity of individual industry sectors and response to weather information.	19.4%
Met Office Revenue*	Revenues of the Met Office. Includes both commercial and non-commercial revenues.	6.1%
Cold Preventable Deaths	Avoided cost approach capturing the value of lives saved due to the Met Office's contribution to cold weather alerts.	3.4%
Winter Transport	Avoided cost approach capturing 'hard' costs (i.e., road and pedestrian accidents and lost economic output) avoided from bad winter weather.	2.7%

Flood/Storm Damage Avoidance	Contribution of Met Office to avoided costs of damage prevented from fluvial and coastal flooding and avoided costs of storm damage prevented.	1.4%
Space Weather	Expected avoided damages to the electricity grid from severe space weather events.	1.1%
International Leadership	Value-chain approach using Met Office data on the payments by other countries for use of Met Offices services/products, specifically the Unified Model.	0.7%
ECMWF	Value-chain approach considering additional expenditure in the UK as a result of having the ECMWF headquarter located in England not elsewhere.	0.6%
Heatwave Preventable Deaths	Avoided cost approach capturing the value of lives saved due to the Met Office's contribution to heat alerts.	0.2%
Government Dividends	Value-chain approach using dividend over and above the HMT Minute target 3.5% return on Capital of the Met Office's operations.	0.1%
Asthma Preventable Deaths	Avoided cost approach capturing health benefits and lives saved for those suffering from asthma as a result of the Met Office's pollen forecasts.	<0.1%
Commercial Catalytic Benefits	Value-chain approach capturing the social return of the Met Office's public science investments in key industry sectors.	<0.1%

Note: This analysis provides the central estimated benefits over the period 2024-2033 of the Met Office's activities for each monetised benefit stream. (*) Revenues are excluded in the estimates of the return on public investment as i) commercial contract revenues are a transfer payment from UK businesses to the Met Office and so have a net-zero benefit to the UK taxpayer, and ii) non-commercial Met Office revenue is predominantly public funded and so while it is a benefit to the Met Office it is a cost to the UK taxpayer.

Source: London Economics

Unquantified benefits

The objective of the study was to bring together, and, where possible, update existing benefit valuations. Where the study team identified existing literature and assumptions which allowed quantification of additional benefits were also included. In particular, the study incorporates a new approach to attribute a share of space weather damages avoided to the Met Office.

However, despite best efforts, a range of non-monetised benefits remain. The presented costs and benefits are therefore an underestimate of the total benefits associated with the Met Office's activities. In particular, the following unquantified benefits should be noted:

- The estimates only consider benefits accruing in the UK. Substantial further benefits as a result of the Met Office's activities also accrue outside of the UK.
- Estimates exclude costs and benefits associated with the Met Office's defence activities as these were outside the scope of this evaluation, due to the sensitive nature of some of the use cases for the Met Office's products and services.
- There are benefits resulting from Met Office activities for which quantification or attribution was not deemed possible within the scope of the study. For example, soft-power benefits for the UK resulting from the Met Office's international standing.

Key differences from the previous evaluation

Monetised benefits estimated using central assumptions in this study are around two-fifths (40%, or £$_{2024}$16.0bn) larger than benefits estimated in the 2015 General Review, when adjusting previous estimates for inflation. The estimated public-benefit-to-public-cost ratio (18.8) are also higher than the 2015 General Review (14.1).

This is due to an increase in the service provision and subsequent benefits, such as space weather damage avoidance, as well as refined evaluation methods for some benefit streams, such as climate adaptation and value to the public. The increase in benefits is somewhat balanced by a rise in costs in the 2024-2033 evaluation, predominantly driven by higher staff costs and supercomputing investments.

There are several key differences that need to be considered when comparing results between these two studies. These are discussed in Section 5.1.1. They include:

- ↑ New primary research focused on the value the Met Office brings to the UK public suggests the **value to the public** is around double that implied by previous literature estimates. Previous literature estimates were very old and did not specifically capture the UK context.
- ↑ **Climate benefits** were updated based on a review of the wider and recently emerged climate literature and the evaluation approach was updated. The results suggest climate adaption and mitigation benefits attributable to Met Office research are likely substantially larger than previously assumed.
- ↑ New literature evidence suggested the assumption on the share of **cold avoidable deaths** used in the 2015 General Review was a substantial underestimate. As a result, estimates of cold preventable deaths have increased significantly.
- ↑ **Space weather** benefits were not included in the 2015 General Review. This study incorporates new estimates of expected damages avoided, attributable to the Met Office, from space weather events to the UK electricity grid.
- ↓ Incorporation of methodological changes to account for behavioural effects to the evaluation of **industry benefits** mean the methodology is more robust than previously. However, these changes resulted in lower estimated central benefits than under the approach used in the 2015 General Review (though as discussed in Box 18, there is a possibility for benefits to be larger).
- ↓ **Defence benefits** are out-of-scope for this study and so are not captured in the total benefits estimates. Defence benefits were estimated at around £1.4bn in the 2015 General Review (£1.8bn in 2024 prices), accounting for just over 4% of previously estimated benefits. Although the methodology employed was a 'replacement costs' estimation, rather than a full benefits estimation.
- ↓ Current best evidence for flood damages avoided is much lower than estimates available in 2015. Moreover, this study made methodological improvements to the value-chain for storm damages. As a result, central estimates of **flood and storm damages** avoided are lower than in the previous study (though again, there is a possibility for benefits to be substantially larger, see discussion in Box 11).
- ↓ **RIMNET** was replaced by RREMS which no longer sits within the Met Office, and so associated benefits are excluded.

In addition, there are a range of potential factors that may lead to larger future benefits than assumed in the central case. Over the course of the ten-year evaluation period, several changes could lead to higher benefits, including:

- the shift in the level of investment in supercomputing,
- opportunities from AI in forecasting,
- new unquantified activities such as the ESA Vigil Mission to launch Europe's first operational space weather spacecraft, and/or
- the increased focus on ensuring Met Office forecasts not only become qualitatively better but are also seen, understood and acted upon by the widest possible audience.

This may mean benefits grow faster than assumed in the central case. However, due to the uncertainty associated with these factors, central results use conservative growth assumptions assuming future benefits will grow in line with previously observed improvements in quality (see Annex A2.4).

Similarly, in a number of cases there was no new robust quantitative evidence to inform updates to key assumptions. While in some cases qualitative evidence suggested that assumptions, and thereby benefits, should have increased, without robust quantitative evidence caution was applied, and conservative estimates used in the central case.

To account for the impact of faster benefit growth as well as increases in the level of benefits, sensitivity analysis was conducted. This analysis suggests that **potential benefits could be substantially larger than implied by the central valuations, highlighting the conservative nature of assumptions used in the central case.**

Comparison to other evaluation studies of meteorological services

A number of similar studies evaluating national meteorological services provide additional context for the estimated benefits and costs for the Met Office. The majority of benefit-to-cost ratios reported in the other studies are between 2:1 and 14:1. Therefore the public-benefit-to-public-cost ratio calculated in this study, 18.8:1, is higher than most similar studies.

However, these studies typically consider a narrower range of activities and benefits, and consequently cannot be expected to deliver benefit-to-cost ratios as high as the UK Met Office with all its activities. Individual studies, alongside short descriptions of the benefits examined, are listed in Section 5.2 in the main body of the report.

The UK Met Office undertakes a wide range of activities and provides services other meteorological services do not necessarily provide. These includes:

- its substantial contributions to climate science and research (and the resulting estimated very large benefits),
- its role as one of only two World Area Forecast Centres (as well as running the London Volcanic Ash Advisory Centre),
- its specialist severe weather warnings and specialist forecasts such as air quality, UV and pollen forecasts,, extreme temperature and space weather forecasts,
- associated work with civil contingencies and emergency response teams, as well as
- its diverse consultancy and advisory activities.

As shown in Table 2, the estimated benefits of some of these streams are large, driving up estimated benefits and thereby the resulting benefit-to-cost ratio compared to a more limited service. As a result, the benefit-to-cost ratio of a more 'basic' offering (9.9:1) whilst remaining at the upper end of the range, would be more in line with those reported in other studies.

The economic value of the Met Office

The economic impact of the Met Office:

Total benefits of Met Office: **56.0 billion over the next decade** with the potential for benefits to be much larger than this already large central estimate)

Return of **£18.8 per £1 of public money invested in the Met Office**

40% increase compared to 2015

How the Met Office is funded:

- Total Met Office funding (revenue) in 2023/24: £274 million
- 59% of funding is managed through DSIT
- The MoD, FCDO and Defra make up 16% of funding
- The Civil Aviation Authority accounts for 13% of funding
- The PWS (Public Weather Service) provides 45% of total Met Office funding

Key Met Office outputs and metrics of interest (2022):

Number of customers 2022: **1210**

Revenue from customers: **£330.8M**

Number of the UK public who trust the Met Office: **83%**

97% of emergency responders trust the Met Office to make decisions and take action

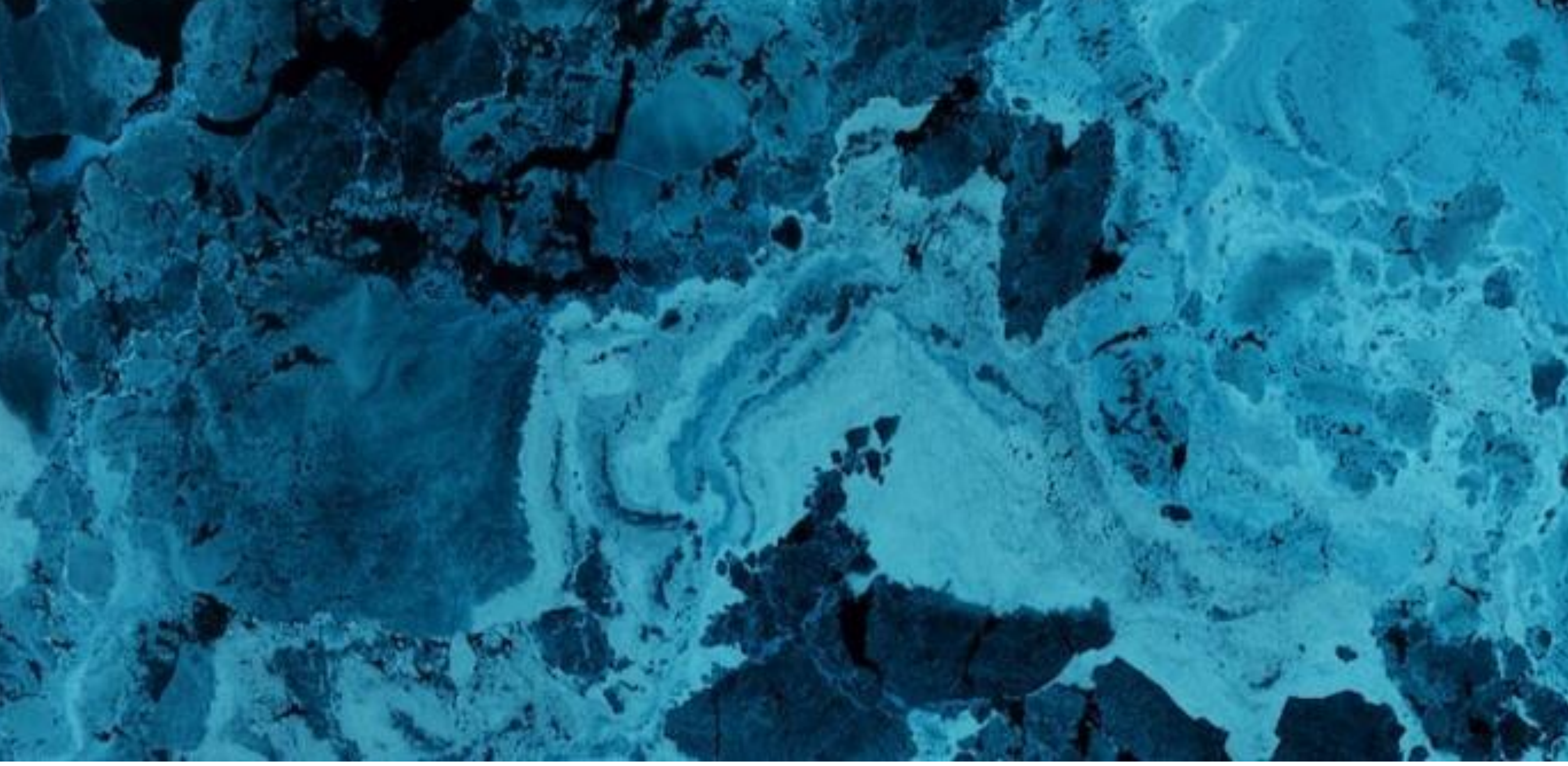
Number of products and services offered: **1100**

Gigabytes of Data publicly provided: **449,414GB**

Number of Severe Weather Warnings in 2023-24 across the UK: **544**

340 scientific publications were authored by the Met Office in 2023-24

Infographic designed by tothepoint



PART I: INTRODUCTION

This part provides:

- A brief introduction to the Met Office, and the study aims and objectives (Section 1).
- Section 2 explores how the Met Office contributes to the UK by identifying:
  - the range of Met Office activities,
  - the benefits deriving from these activities,
  - the inputs and enabling activities underpinning the Met Office's services (summarised in Box 2, p. 6), and
  - the link between inputs, activities, and benefits - the Met Office's production function.
- The Met Office's inputs, activities and resulting benefits are then summarised in the form of a Theory of Change (Figure 2, p. 8).

Image credit: Met Office - Momentum - weather and climate model

1 Introduction and objectives

In May 2023, London Economics was commissioned by the Met Office to undertake **an evaluation of the economic value of the Met Office's activities to the UK**. The current study updates the Met Office General Review (London Economics, 2015).

The Met Office is an executive agency, sponsored by the Department for Science, Innovation and Technology. It is the UK's national meteorological service providing **weather and climate research and services** to the UK public, industry, governmental departments, and other organisations **to help people make better decisions to stay safe and thrive**. In addition to weather and climate information, the Met Office provides a wide range of services, including:

- **Provision of the Public Weather Service** (PWS) providing meteorological, climatological, and associated services and underpinning or supporting most Met Office activities.
- The **Unified Model**, a numerical model of the atmosphere used for both weather and climate applications.
- The **National Severe Weather Warning Service**, providing advance warnings of critical weather events such as floods, storms, and extreme heat, and important partnerships such as the **Flood Forecasting Centre**, a partnership between the Met Office and the Environment Agency, and the **Heat-health Alert service,** provided in partnerships by the UK Health Security Agency (UKHSA) and the Met Office.
- **Specialist forecasts and mission-critical advice to the UK defence sector** (out of scope for this study).
- **Supports UK civil contingencies**, engaging with and providing advice to central government and local resilience groups.
- **Seasonal advice and warnings** such as air quality, pollen, and UV forecasts helping individuals make better decisions and increase their quality of life.
- Regulatory mandated **weather information to the UK aviation sector.** The Met Office is **one of two World Area Forecast Centres** (WAFC) for global en-route weather information, and one of nine Volcanic Ash Advisory Centres (VAAC).
- Providing **climate change adaptation and mitigation advice and support** to local and central government, key national infrastructure providers, industry, and other organisations, and home to the **Met Office Hadley Centre for Climate Science and Services**.
- One of a handful of operational 24/7 staffed **space weather centres around the globe**, working with international partners to develop accurate space weather forecasts.
- **Education and outreach activities**, including the **Public Weather Media Service** (PWMS), a package of free UK weather services for eligible UK Broadcasters, facilitating reach and usefulness of publicly provided weather and climate information.
- **Provision of open- and bespoke data, forecasts and other services** to government, commercial and private users.

The Met Office is at the global forefront of meteorological and climate science, working in partnership with leading academics and other meteorological offices. Indeed, the Met Office frequently provides the **"pathway to impact"** for academic research, by utilising cutting-edge research in the delivery of the operational services it provides. The Met Office further engages with and contributes to a number of **international partnerships and organisations** such as the European Centre for Medium-Range Weather Forecasts (ECMWF) and works with other organisations to deliver impactful **international development projects.**

1.1 Study objectives and scope

The study **provides an economic impact assessment of the Met Office's total contribution to the UK economy, society and government over the coming ten-year period** (2024 to 2033). The following steps were taken:

- A **Theory of Change** (ToC) for the Met Office was developed. The ToC presents an overall map of the Met Office's socio-economic benefits.
- To estimate the Met Office socio-economic benefits a **counterfactual scenario** was established. The counterfactual sets a baseline from which the benefits are evaluated.
- **Existing benefit valuations** were updated where possible with the most recent available data. The study also considered how a **'life saved' approach** can be captured in a wider range of values than that done in Met Office General Review (2015). The approach used to value 'life saved' in this study is discussed in detail in Annex A2.1.2.
- Provide **aggregate impacts** and calculate the Met Office's overall net impacts including benefit-to-cost ratio and **return on investment** and, where possible, make a **distinction between** the impacts of **publicly funded and commercially funded** work of the Met Office.
- Provide **2-3 case studies** demonstrating how Met Office products and services create social value now or in the future.

Non-UK benefits and defence benefits are outside the scope of this study. Moreover, as the main objective of the study is to bring together and update existing valuations, new benefit streams are only captured where the study team has identified existing literature. Where gaps were identified, these have been highlighted and potential ways forward identified. In some cases, where gaps could easily be addressed, changes were integrated into the valuation approaches. However, where substantial additional work would have been required, this was considered outside the study scope.

One exception is a bespoke study the Met Office has commissioned on the Value of the Met Office to the public which is included in the valuations presented in this report. Finally, while benefits associated with the Met Office's climate science activities taking place at the Met Office Hadley Centre (MOHC) are included in this study, they are explored in greater detail in a parallel evaluation study of the Hadley Centre, for the Department for Energy Security and Net Zero (DESNZ).

2 How the Met Office contributes to the UK

2.1 The range of Met Office activities benefitting the UK

The Met Office undertakes a wide range of activities contributing to the UK. These activities are aligned with the Met Office's core purpose and vision, namely:

- Helping you [i.e., individuals, industry and other organisations, governmental departments and other public bodies, and other actors] make better decisions to stay safe and thrive (the Met Office's purpose); and,
- to be recognised as global leaders in weather and climate science and services in the changing world (the Met Office's vision).

As the UK's national meteorological office, a key service the Met Office provides is accurate and easily accessible weather and climate information. In addition, the Met Office provides a wide range of further activities, products, and services for both government and industry.

For this study, related activities and resulting benefits were grouped into five categories. These are briefly outlined below. Further detail on the range of the Met Office's activities under each of these groupings is provided in Sections 6 to 10.

Weather services	The first category captures the Met Office's **weather services** and **activities**. This includes **weather information** and **forecasts**, **seasonal advice**, **warnings** such as pollen, flooding, UV, or air quality forecasts, and the Met Office's **National Severe Weather Warning Service**. They also include Met Office support for UK **civil contingency**, **specialist meteorological advice** to **governments**, other **public bodies** and **specialist weather forecasts,** and **modelling** such as the Met Office's dispersion models and its space weather forecasts.
Climate services	The second category captures the Met Office's **climate services** and **activities**. This comprises of the **provision** of **climate information** and **climate projections** such as the **UK Climate Projections** (UKCP). The Met Office also provides a range of additional climate related services. For example, the Met Office works with government, other national and international bodies, and industry to plan for and support climate change adaptation.
Benefits to industry[3]	Provision of weather and climate information directly benefits **industry**, for example, by **supporting planning decisions** for upcoming weather events. In addition, the Met Office also provides a range of **specialist services** to industry. Generally, these include **regulatory mandated services** to the aviation sector including en-route provision of weather information, aviation briefings, and advice related to volcanic ash. The Met Office also provides **advisory** and **consultancy services** to industry. These services encompass a wide range of activities. For example, modelling of marine ingress and flooding to support the nuclear industry. They also work with the National Grid and energy providers to support improved demand and supply management in the energy grid, and meteorological advice to the offshore industry to safely construct or service offshore infrastructure. They also provide a range of other industry-specific services to government and other public bodies.
Science, innovation and technology	As highlighted by its vision, the Met Office also undertakes a wide range of **scientific**, **innovation** and **technology** related activities. This includes the Met Office's **weather** and **climate science** and **research programmes**. Moreover, it includes the Met Office's **enabling activities** such as those related to its ground-based observations and satellite EO data, and its contribution to the Vigil mission. The Vigil mission is an ESA mission that aims to significantly increase space weather forecasting capabilities. It also includes the Met Office's wider technological and innovation related activities such as tech/innovation partnerships and data provision.
Other key activities	Finally, the Met Office undertakes a range of **other key activities** not captured by these four broad groupings. These include the Met Office's **defence-related** activities (not in scope for this study), its **international partnerships** and **development activities**, and its **public engagement** and **outreach** activities, among others.

[3] Benefits to industry have been split out into a separate grouping due to the substantial monetised benefits accruing in this area. The Met Office also provides important advisory and consultancy services to government, local responders and other public bodies. Hence, another grouping could have been, e.g., into core climate/weather services, services to government/public bodies, services to industry. However, these are often either captured in the valuation of activities of weather and climate services and difficult to disentangle (e.g., climate mitigation advice to government would be captured by climate mitigation benefits) or difficult to capture/unmonetised.

2.2 The range of benefits deriving from the Met Office's activities

In line with its purpose, Met Office products and services help the UK public, industry, government and other bodies make better decisions. This enables citizens and organisations to stay safe and thrive.

The Met Office also provides wider benefits to the economy, society, environment, science, as well as the international standing of the UK.

Benefits can be grouped **based on** the **expected time** it takes for them to materialise **and how tangible** these benefits are (e.g., direct research outputs such as number of publications vs. soft power benefits from improved international standing of the UK). Concretely, benefits can be split into groups presented in Table 3.

Table 3 Benefit groupings by time period

Group	Types of benefit

Outputs and short-term outcomes	This grouping captures direct outputs and short-term outcomes. Examples include:
	▪ Direct benefits from Met Office activities:
	  ▫ provision of weather/climate information,
	  ▫ weather/climate related data, and
	  ▫ research outputs (e.g., publications, risk assessments, and advice).
	▪ Direct benefits resulting from the Met Office as a major employer (e.g., job creation and training).
	▪ Direct revenue generated through the Met Office's commercial activities and benefits to the private weather sector who take Met Office outputs and deliver commercial services for revenue/profit.

Medium-term outcomes	This grouping captures intermediate outcomes arising over the medium-term. Examples include: ▪ increased public welfare resulting from better decisions made as a result of access to better weather information; ▪ health benefits and lives saved through provision of the Met Office's extreme weather warnings; ▪ knowledge creation and technological innovation resulting from the Met Office's scientific and research activities and technological partnerships; ▪ intermediate benefits to industry.
Longer-term outcomes and impacts	These are less tangible, but nonetheless very important, benefits arising over the longer term. Examples of long-term outcomes and impacts include: ▪ the Met Office's and UK's standing as a world-leader in meteorological and climate science research; ▪ increased resilience against environmental risks such as flooding; ▪ improved resilience to and better management of climate change; ▪ wider benefits to industry, for example, through improved decision-making, and economic growth.

The benefits and impacts resulting from each the Met Office's key activity groupings are also explored in further detail in Sections 6 to 10.

2.3 Inputs and enabling activities underpinning the Met Office's activities and benefits

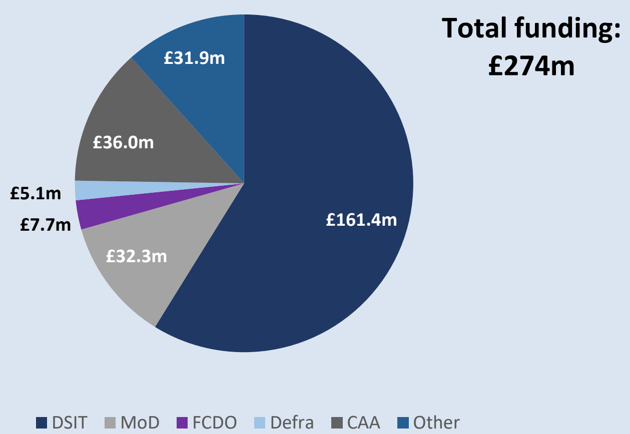
To deliver its products and services the Met Office relies on a range of key inputs. This includes the Met Office's expert meteorologists and scientists, its infrastructure (including supercomputing and observations), and its partnerships. Without these the Met Office would be unable to provide world-leading meteorological information and undertake its other key activities.

Another key input is public funding. While the Met Office is a trading fund, so it can generate some revenue, it is not profit-maximising. As such the Met Office relies on public funding to provide its activities. Box 2 provides a high-level overview of how the Met Office is funded.

Box 2 How the Met Office is funded

The majority of funding for the Met Office's services comes from the Department for Science, Innovation and Technology (DSIT, 59%). The funding managed through DSIT includes funding for the Public Weather Service (PWS)[4], the Hadley Centre Climate Programme (HCCP), the Weather and Climate Science for Service Partnership Programme (WSCCP), Strategic Priorities Fund (SPF), space weather, and RIMNET[5]. The Met Office also receives funding for its supercomputer through a separate grant from DSIT (see section 4.2).

Figure 1 Met Office Budget - funding split (£m), financial year 2023/24



Note: Excludes funding for the Met Office's supercomputing capabilities. Totals may not add up exactly due to rounding.

Source: Met Office Financial Overview May 2023

Funding from the Ministry of Defence (MoD), the Foreign, Commonwealth and Development Office (FCDO) and the Department for Environment, Food & Rural Affairs (Defra) make up around 16% of Met Office funding. In addition to public funding, the Met Office also receives funding from the Civil Aviation Authority (CAA, 13%) and other smaller contracts.

[4] The Public Weather Service is an umbrella term that captures the means by which the Met Office fulfils its Public Task as the UK National Meteorological Service. This broadly includes provision of meteorological, climatological and associated service, as well as ancillary services needed to deliver these meteorological, climate and associated services. However, the PWS underpins or supports almost all Met Office activities in some way or other.

[5] RIMNET is transitioning to the Radiological Response and Emergency Management System (RREMS) managed by the Department for Energy Security and Net Zero and so is not evaluated in this study.

In addition, the Met Office relies on a range of enabling activities to deliver its products and services. These activities include gathering of observational data, pre- and post-processing, and modelling. To distinguish these activities from the Met Office's products and services described earlier, this study makes a distinction between downstream activities (referring to the activities described in Section 2.1) and enabling activities (activities needed to enable downstream activities).

2.4 The link between inputs, activities, and benefits: The Met Office's Theory of Change

The causal chain between the Met Office's activities and impact and its purpose and vision can be formalised through a conceptual model. The model used for this study is the Theory of Change (ToC). The ToC approach is a widely used framework to develop the conceptual model in evaluation studies for central government. It is one of the best practice approaches to evaluation scoping outlined HMG's Magenta Book (HM government, 2020), which provides best practice central government guidance on evaluation[6].

The ToC establishes the link between the Met Office's activities and the intended immediate outputs and both short and longer-term outcomes and impacts. Outcomes and impacts are therefore linked to the Met Office's purpose and strategic vision. In addition, the model accounts for the inputs necessary for the Met Office to undertake its activities and deliver benefits.

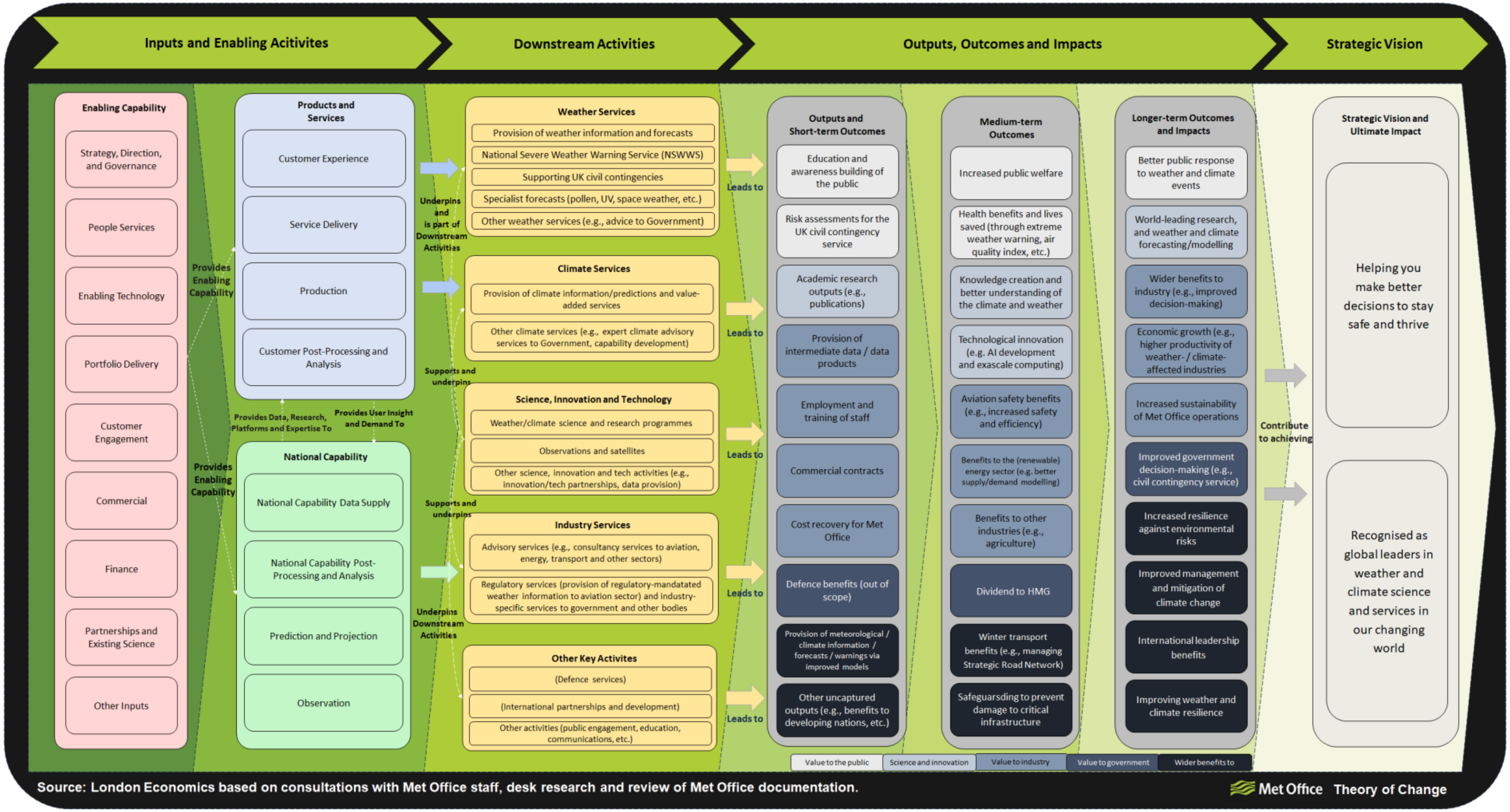
2.4.1 Met Office Logic Model

A key component of this Theory of Change is the logic model. The logic model provides a high-level graphical overview of inputs, activities, outputs, outcomes and impacts across the Met Office's activities and sectors. The Met Office's logic model developed for this study is provided in Figure 2.

For each of the Met Office's key downstream activities, impact pathways illustrate the specific inputs, activities, outputs, outcomes and benefits associated with each downstream activity (Sections 6 to 10).

[6] The Magenta Book also provides a good and digestible introduction to the ToC approach. Therefore, readers unaware of the methodology should refer to the Magenta Book for further detail.

Figure 2 Met Office logic model



Source: London Economics

2.4.2 The Met Office's production function: formalising the mechanisms through which inputs and enabling activities deliver benefits

To formalise the causal link between inputs and benefits, a production function approach can be used. A production function describes the relationship between outputs (or benefits) and inputs.

Key inputs include the Met Office's meteorological observations, supercomputing capabilities, and expert meteorological staff. These inputs are all needed to deliver the Met Office's activities. Moreover, each of these key inputs are necessary. That is, in the absence of any one of these inputs the Met Office would be unable to provide its services, and therefore no benefits would be achievable.

Given the Met Office's specific reliance on its supercomputer, satellites, and other enabling capabilities, the relationship between Met Office inputs and outputs (benefits) is best thought of in terms of a Stone-Geary production function (developed in Geary and Roy, 1950). Unlike in other production functions, in a Stone-Geary production function there exists a minimum threshold of inputs below which the production of outputs and realisation of benefits would not be possible. That is, minimum levels of inputs reflect that the Met Office would be unable to deliver key services and resulting benefits without key inputs, particularly the core enabling function of the Met Office's underpinning national capability.

To illustrate this, one can consider a Met Office without a supercomputing capability. While it would still have access to expert meteorological staff and observation data, the services the Met Office could provide would be severely restricted as it would be unable to run its sophisticated meteorological models. Similarly, without sufficiently expert staff who are capable of running, understanding and interpreting the models, the Met Office could provide would be severely limited.

Technological and scientific advancement also play a role. Just like a two-decade old desktop computer, a supercomputer that was fit for purpose twenty-years ago would have degraded in capability over time. Eventually, it would no longer be able to keep up with modern technological demands, and the Met Office would be unable to run its models. Similarly, continuous investments need to be made to ensure the Met Office has the observational data it needs. Models also need to be maintained, and meteorologists need to keep up with evolving meteorological science. Therefore, to continue to deliver benefits to the UK, the Met Office needs to ensure its technology is fit for purpose.

Further details on the Met Office's Theory of Change, including a more detailed exploration of the Met Office's production function, are provided in Annex 1. The Stone-Geary production function provides a useful framework to think about, and an explanation of the relationship between Met Office inputs and benefits. The more detailed exploration provided in Annex 1 is a useful conceptual tool to consider.

At the same time, the production function is only a conceptual model, and its real-world application is limited to how well it describes reality. Expressing the relationship between outputs and inputs in the production function in precise quantitative terms is not only difficult, but reducing complex relationships to an overly simplistic algebraic formulation can be misleading. Therefore, important investment decisions should be based on a detailed benefit to cost analysis of the specific decision, not a simplistic model conceptual model.

PART II: UPDATED ECONOMIC VALUATION OF THE MET OFFICE

This part provides:

- An overview of the **benefit valuation approach** (Section 3) including:
  - the value streams considered and valuation approaches;
  - the link to the Theory of Change; and,
  - a high-level discussion on the selected counterfactual.
- Updated **evaluation results** of the economic value of the Met Office to the UK (Section 4) including:
  - the central valuations of monetised impacts (aggregate and by benefit stream); and,
  - an evaluation of Met Office costs and revenue, including public investment in the Met Office.
- An **assessment of the magnitude of the estimated benefits** (Section 5), including:
  - the results of the sensitivity analysis highlighting the magnitude of uncertainties around the central estimates;
  - an assessment of how evaluated benefits have evolved from the previous General Review; and,
  - a comparative assessment of estimated benefits to other economic evaluation studies of meteorological services.

Image credit: Valeri Potapova/shutterstock

3 Approach to valuing benefits

Section 3.1 provides a brief overview of the approach to valuing benefits, as well as an overview of the evaluation method for all benefit streams identified in Part I. Section 3.2 briefly discusses the chosen baseline and counterfactual scenarios against which benefits are assessed (see A2.5 for more detail on the counterfactual scenario).

3.1 Overall approach and evaluation methods for key benefit streams

Overarching approach to valuing benefits: The key objective of this study is to bring together and update existing valuations of the Met Office's impact. Therefore, the approach taken focused on reviewing, evaluating, and updating valuations from the 2015 General Review. A review of the methodology and assumptions for each benefit stream used in the 2015 General Review was undertaken. In addition, a review of recently published literature and consultations with Met Office experts and external stakeholders were completed, to verify whether the methodologies and assumptions used are still optimal. Based on the review and consultations, an evaluation framework was developed. Where more up-to-date or more robust evidence was identified, these have been incorporated. Details on the approaches used to evaluate each benefit stream are presented in the methodological annex (Annex 2).

Benefit stream overview: Table 4 (overleaf) provides an overview of the benefit streams evaluated in this study. Downstream activities that are not monetised are also included in this table. These highlight gaps in the monetised benefits. For the non-monetised downstream activities, a series of qualitative case studies are provided.

The link to the Theory of Change: Benefit streams have been placed in a new framework, the Theory of Change (ToC) described in Section 2.3, developed for this study. In the ToC, value streams are linked to their corresponding downstream activities (and activity groupings). These groupings also form the basis for the detailed exploration of benefits in Part III. The ToC provides the link between monetised benefits and the overall benefit framework. It also enables gaps to be highlighted more easily.

Relationship to benefit streams in previous study: Benefit streams evaluated in the 2015 General Review were predominately based on key sectors and activities and focused on areas expected to deliver large benefits. The new ToC provides a firm theoretical foundation that encompasses all Met Office benefits and impacts including those that are not monetised. Further, the ToC explores how activities and inputs lead to impacts, and a production function is used to link inputs to benefits.

Avoidance of double-counting: Due to the holistic nature of the Met Office's service provision, there are activities which the Met Office undertakes that lead to benefits across multiple areas. Wherever possible, 'double counting' has been minimised, i.e. the benefits from one activity are counted in more than one benefit stream estimate (for more detail please see A2.6.2). For example, consultancy activities are not quantified as a benefit stream because the benefit of these activities to users are captured in other benefit streams.

Table 4 Benefit streams and evaluation approach

Activity grouping	Activity	Benefit stream	Valued in 2015	Valued in 2023	Other evaluations / approaches considered	Evaluation approach used in 2024 study
Weather services (Section 6)	Provision of (public) weather information (Section 6.1)	Value to the Public (Section 6.1)	✓	✓	Buchanan (2012)	Perception of value based on willingness-to-pay survey (London Economics, 2024)
	Extreme weather and supporting civil contingencies (Section 6.2)	Flood damage prevention (Section 6.2.1)	✓	✓	Economic analysis of General Review (2015), Environment Agency (2015), Radar Benefit Model (2018), Ross (2019b)	Avoided cost approach capturing the prevented damage from fluvial and coastal flooding following London Economics (2015) with uplifts applied based on specific costs related to vehicle damage, health and wellbeing and emergency services
		Storm damage prevention (Section 6.2.1)	✓	✓	London Economics (2017), ABI (2022)	Avoided cost approach capturing the prevented storm damage from information provided (e.g., weather warnings), broadly following London Economics (2015) with improved attribution assumptions.
		Lives saved from extreme heat / cold weather alerts (Section 6.2.2)	✓	✓	London Economics (2019)	Avoided cost approach capturing the value of lives saved following London Economics (2019)
	Specialist forecasts (Section 6.3)	Health benefits and lives saved (asthma, air quality, etc.) (Section 6.3.1)	✓ (partially)	✓	London Economics (2019)	Avoided cost approach following London Economics (2015)
		Space weather damage avoided (Section 6.3.2)		✓ (partially)	Oughton et al. (2019)	Based on existing literature on space weather damages that can be avoided, e.g., Oughton et al. (2019). Avoided cost approach with attribution of total cost avoided due to Met Office services
Climate Services (Section 7)	Climate Services (Section 7)	Climate change adaptation benefits (Section 7)	✓	✓	Hope (2013), London Economics (2015), UCL (2019)	Avoided cost approach based on the mitigation and adaptation benefits of receiving climate change information earlier, following London Economics (2015)
Industry benefits (Section 8)	Provision of weather information to industry (Section 8.1)	Impact of provision of weather information on industry ('Other' business sectors, Section 8.1)	✓	✓	B2B International (2018), London Economics (2016), World Bank (2021), Ross (2019a), Andalus Solutions (2013)	Value-chain-approach based on weather sensitivity of industry sectors and response to weather information following Ross (2019a). Only captures 'other' business sectors – i.e., those where benefits are not evaluated directly.
	Consultancy & advisory activities (Section 8.2)	Value of the Met Office's consultancy activities (Section 8.2)			-	This benefit stream was not evaluated to avoid double counting with other streams. Commercial contract revenue is counted in total revenues.
	Sector specific industry impacts (Section 8.3)	Value of regulatory aviation services - World Area Forecast Centre (Section 8.3.1)	✓	✓	Helios (2019)	Market-based estimate following London Economics (2015), accounting for updated figures from Helios (2019)
		Value of weather forecasts to aviation (Section 8.3.1)	✓	✓	Helios (2018)	Avoided cost approach following London Economics (2015) and based on Helios (2014 & 2018)

Activity grouping	Activity	Benefit stream	Valued in 2015	Valued in 2023	Other evaluations / approaches considered	Evaluation approach used in 2024 study
		Winter Transport benefits (Section 8.3.2)	✓	✓	Winter Resilience Review (2010), London Economics (2015)	Avoided cost approach based on costs of bad winter weather and proportion of costs avoided due to response to Met Office weather forecast following London Economics (2015)
Science, innovation and technology (Section 9)	Weather/climate science and research (Section 9.1)	Wider benefits from scientific research & discovery (Section 9.1)			Haskel et al (2014), Frontier Economics (2023)	Qualitative, indicative (e.g., no. of publications) to avoid double-counting
	Satellites, tech, observation, data provision and innovation (Section 9.2)	Impacts of supercomputer, satellites and other observations, data provision and innovation (Section 9.2)			-	Qualitative. Enabling capabilities contribute to all Met Office benefits. As such, they are not evaluated separately to avoid double counting.
		Commercial catalytic benefits (Section 9.2)	✓	✓	Haskel et al (2014)	Value-based approach using data on Met Office investment in industries and social return on those investments following London Economics (2015). Narrow estimate to avoid double counting.
Other key activities (Section 10)	International partnerships and development (Section 10.1)	European Centre for Medium Range Weather Forecasts (ECMWF) benefits (Section 10.1)	✓	✓	General Technology Systems (1995), CITIZING (2017)	Value-chain approach using cost data from the ECMWF Annual Report (2022) and expenditure data provided by ECMWF/Met Office, following the approach by London Economics (2015)
		International leadership benefits (Section 10.1)	✓	✓	-	Value-chain approach using Met Office estimates on the value of Met Office science partnerships.
		International development activities and other international partnerships (Section 10.1)		NA – out of scope	-	Qualitative/indicative (as out of scope as benefits accrue outside of the UK)
	Defence services (Section 10.2)	Defence and security benefits (Section 10.2)	✓	NA – out of scope	-	Qualitative
	Other activities (public engagement, etc.) (Section 10.3)	Government dividend benefits after return on capital (Section 10.3)	✓	✓	-	Value-chain approach following London Economics (2015) using dividend over and above the HMT Minute target 3.5% return on Capital of the Met Office's operations
		Wider government avoided cost due to centralised Radioactive incident monitoring Network (RIMNET) delivery by Met office (-)	✓		-	NA – no longer sits with Met Office

Source: London Economics

3.2 Selected counterfactual(s)

One of the most important activities for any evaluation is to define the 'baseline' and 'counterfactual' scenario(s). These scenarios form the basis of the analysis. The socio-economic benefits and costs of the baseline scenario are assessed relative to the counterfactual.

The Met Office wishes to understand its **total contribution to the UK economy, society, and government over the period 2024-2033**, and this forms the **baseline scenario**. A distinction is made between the impacts of the publicly funded and commercially funded work of the Met Office.

The **counterfactual** can be defined in numerous ways, each with their own advantages and disadvantages. To maintain similarity with the 2015 General Review, a 'do-nothing' and a 'do-minimum' counterfactual was chosen:

- Under the **do-nothing** counterfactual, the baseline or existing benefits and costs of the Met Office (referred to as the 'Existing' Met Office baseline scenario or 'central scenario') are evaluated relative to a situation in which no meteorological services are provided by the Met Office.
- The **do-minimum** counterfactual assumes the Met Office only provides a 'basic' level of services (referred to as the 'Basic' Met Office scenario) to meet international obligations and national obligations, such as the requirements under the Civil Contingency Act.

These scenarios are **hypothetical**, and are not necessarily realistic. In practice, due to international obligations and the Met Office's long history and international standing, it is highly unlikely that the Government would close down the Met Office. Whilst the 'do nothing' world does not exist in practice, it allows for an estimation of the full magnitude of benefits associated with the 'Existing' Met Office.

Similarly, the do-minimum scenario is a hypothetical scenario which explores the impact of a hypothetical reduction in service provision. In reality, a restructuring is complex, would likely take several years, and would incur additional costs (such as redundancy costs, transaction costs for moving to smaller premises, etc.) which are not modelled.

Crucially, the Met Office's new supercomputing contracts are already predetermined. Therefore, while a more basic service would not need the increased supercomputing capabilities (and thus the modelled hypothetical scenario assumes a lower supercomputing cost, see Annex A2.5), the costs would still be incurred over the agreed time-horizon and the realised benefit to cost ratio would therefore be substantially lower in the transition period.

Another factor to consider is whether in a do-nothing or do-minimum world the activities and services currently provided by the Met Office would be provided by an alternative organisation such as the private sector or meteorological services from other countries. This is known as **additionality** and is explored in greater detail in Annex A2.5.3. However, it is worth noting that given the Met Office's enabling role and the high investments needed to replicate its capabilities, it is unlikely that the private sector or other organisations would step-in to deliver the wide range of services provided by the Met Office (though they may provide some).

Box 3 What constitutes a 'Basic' Met Office?

The do-minimum scenario is a hypothetical scenario which explores the impact of a hypothetical reduction in service provision. Specifically, this scenario assumes that the Met Office would no longer provide the breadth and depth of services it currently provides but instead provides a more 'basic' meteorological service.

Under this scenario, the Met Office continues to provide weather information and forecasts to the public, though these would be of a lower quality. The Met Office would also continue to exchange meteorological information and observational data with international partners and fulfil its regulatory-mandated responsibilities to the aviation sector.

However, other services such as the Met Office's climate services, and specialist services such space weather forecasts would not be provided. This means that:

- The Met Office would no longer provide its commercial and advisory activities, and significant scaling back of international leadership and collaboration activities.
- Closure of the Hadley Centre for Climate Science and Services, and cessation of provision of climate-related services.
- Removal of the global model and reliance on models from other organisations (ECMWF).
- As a result, there would be lower forecasting ability and associated impacts on quality of other services.
- While the Met Office would continue to provide its regulatory-mandated services to the UK aviation industry, it would no longer be able to support provision of a World Area Forecast Centre. It would also no longer be able to act as a Volcanic Ash Advisory Centre.

Crucially, a more basic service would lose many of the soft-power benefits associated with a world-leading meteorological service. Many of these benefits could not be quantified, and so are not quantitatively reflected in the modelling of the basic service.

In addition, the Met Office would no longer be able to provide its critical defence services with significant knock-on effects to a range of critical national services (out of scope and therefore not explore further in this study).

Further details on which benefits and costs were included/excluded in the do-minimum scenario as well as the modelling assumptions made are provided in Annex A2.5.

4 The economic value of the Met Office

This section presents the central valuations of the overall economic benefits, to the UK, and costs associated with the Met Office's activities over the next decade (2024-2033). All costs and benefits are presented in 2024 real discounted prices, using the HM Treasury Green Book discount rate of 3.5%. Uncertainties surrounding the central estimates are highlighted. An in-depth discussion is provided in Section 5.1, which presents the results of the sensitivity analysis.

4.1 Aggregate monetised impacts - central valuations

Using the central assumptions, the **total present benefits of the Met Office's activities over the next decade (2024-2033) are estimated to be in the region of £56.0bn**. The total present costs associated with the Met Office's activities is around £3.5bn. The central estimate of the Met Office's net present benefits is therefore £52.6bn **with a benefit-to-cost ratio of 16.1** (Table 5).

The results of the sensitivity analysis (see Section 5.1) suggest that these estimates are on the conservative side. As shown in Figure 3 in Section 5.1, the estimated benefit distribution exhibits a long right tail. This means that **there is a possibility for the total benefits to be much larger than those estimated** using the central assumptions.

In addition, **there are potentially substantial non-monetised benefits which have not been quantitatively evaluated for this study** (discussed in Box 4).

Table 5 Met Office Benefits: Aggregate central results

Benefits		'Existing' Met Office	'Basic' Met Office
Total present benefits	b_1	£56.0bn	£24.6bn
of which private benefits accruing to the Met Office (i.e., Met Office revenue)		*£3.4bn*	*£2.3bn*
Total present benefits to the UK economy	b_2	**£52.6bn**	**£22.4bn**
Costs		**'Existing' Met Office**	**'Basic' Met Office**
Total present costs	c_1	£3.5bn	£2.3bn
of which not covered by public funding (i.e., covered by Met Office's commercial activities)		*£0.7bn*	-
Total present public investment	c_2	**£2.8bn**	**£2.3bn**
BCR and net present benefits		**'Existing' Met Office**	**'Basic' Met Office**
Benefit-to-cost-ratio (incl. private benefits)	b_1/c_1	16.1	10.9
Net present benefits (incl. private benefits)	b_1-c_1	£52.6bn	£22.4bn
Return on public investment		**'Existing' Met Office**	**'Basic' Met Office**
Total benefit per £ of public investment	b_2/c_2	**18.8**	**9.9**
Net present benefits to the UK economy	b_2-c_2	**£49.8bn**	**£20.1bn**

Note: This analysis provides the estimated benefits, over the period 2024-2033, of the Met Office's activities relative to the total costs of the Met Office. The analysis of total costs and benefits includes all Met Office costs as well as commercial contract revenues received by the Met Office. However, part of these benefits accrue to the Met Office privately (i.e., Met Office commercial revenues and non-commercial revenue - such as public funding received by the Met Office) and so are not a benefit to the UK economy. This is because i) commercial contract revenues are a transfer payment from UK businesses to the Met Office and so have a net-zero benefit to the UK taxpayer, and ii) non-commercial Met Office revenue is predominantly public funded and so, while it is a benefit to the Met Office, it is a cost to the UK taxpayer. Similarly, not all the Met Office's costs are carried by the public purse. Therefore, the analysis of the return on public investment removes these costs and benefits to derive the benefits of the Met Office's activities to the UK economy relative to the amount of public received by the Met Office (i.e., the actual cost carried by the public purse). The return on public investment is calculated as a benefit-to-cost ratio (BCR) - i.e., public present benefits : present public investment. This measure is commonly used in Green Book analyses. However, it is not a return on investment in the sense used in financial analysis where net return factors in costs. Rather, it should be interpreted as a gross return with a BCR greater than 1 indicating that the benefits exceed the costs.

Source: London Economics

Return on public investment in the Met Office

The central results presented in the previous paragraphs include all the Met Office costs (excl. defence-related costs) as well as the Met Office's public revenue (i.e., public funding received which is a revenue to the Met Office) and the commercial revenue the Met Office receives from its consultancy and advisory activities.

However, revenue received by the Met Office is not a benefit to the UK economy more generally. Similarly, not all Met Office costs are carried by the public purse. Therefore, Table 5 also provides the central results considering, as costs, only the public investments (i.e., funds invested into the Met Office by the public purse) in the Met Office and excluding, from benefits, public and commercial contract revenues (as transfer payments).

The total present public investment in the Met Office (i.e., excluding costs not carried by the public purse) is estimated to be around £2.8bn over the next decade. In comparison, the total estimated present benefits to the UK economy (excluding transfer payments) is approximately £52.6bn. This implies a **total present benefit to the UK economy of £18.8 for every £1 of public money invested in the Met Office.**

This estimate is larger than the benefit-to-cost-ratio quoted before. This is because, as a trading fund, the public does not carry all Met Office costs. Costs to the public purse are around one-fifth smaller than total Met Office costs, with the remaining share of costs funded through the Met Office's commercial activities. While benefits are also smaller, as private benefits to the Met Office are excluded in this analysis, the reduction in costs to the public outweighs the reduction in benefits.

Box 4 Unquantified benefits

The objective of the study was to bring together, update with the most recent available data where possible, existing benefit valuations of the Met Office. Where the study team identified existing literature and assumptions allowing quantification of additional benefits these were also included. However, despite best efforts a range of non-monetised benefits remain. The presented costs and benefits are therefore an underestimate of the total benefits associated with the Met Office's activities. In particular, the following unquantified benefits should be noted:

- The estimates only consider benefits accruing in the UK. Substantial further benefits as a result of the Met Office's activities also accrue outside of the UK.
- Estimates exclude costs and benefits associated with the Met Office's defence activities as these were outside the scope of this evaluation.
- In addition, there are potentially substantial non-monetised benefits accruing in the UK. This includes benefits resulting from Met Office activities for which quantification or attribution was not deemed possible within the scope of the study (e.g., soft-power benefits for the UK resulting from the Met Office's international standing, benefits related to in-space safeguarding of satellite from debris).
- A range of benefits were also specifically excluded from the evaluation to avoid potential double counting with other streams (e.g., benefits accruing to the insurance and finance sectors, benefits to the land transport sector in the summertime, societal returns on academic research).

'Existing' vs. 'Basic' Met Office

Due to the reduction in services and the assumed lower quality of the services provided by a 'Basic' Met Office[7], benefits under this scenario are lower. The central estimate suggests a reduction in benefits of around two-fifths (40%) to £24.6bn. However, the Met Office costs in this scenario would also be lower. The central assumptions suggest a reduction in costs of around £1.2bn. This is mainly driven by the assumed lower costs of supercomputing needs and reduction in headcount[8].

The analysis of benefits and costs implies a reduction in the benefit-to-cost-ratio from 16.1 to 10.9. However, as a more basic Met Office is assumed not to provide its specialist consultancy and advisory services, the total costs under this scenario are assumed to be carried by the public purse. Therefore, the estimated public present benefit : public present cost ratio is substantially lower than under 'Existing' service provision (9.9 vs. 18.8).

Key drivers of this reduction are:

- The closure of the Hadley Centre and associated loss of climate benefits – accounting for nearly two-fifths (38%, or £12.0bn) of the reduction in benefits.
- Loss of the Met Office's function as a World Area Forecast Centre and reduction in quality of remaining aviation services – accounting for 22% (£7.0bn) of the reduction in benefits.
- Reduction in quality of weather information provided to the public and industry – accounting for 13% of the reduction in benefits each (£4.2bn for the value to the public and £4.0bn for benefits to other business sectors).

Moreover, the sensitivity analysis suggests that the potential upside of benefits in this scenario would be more limited. This is because the estimated sensitivity distribution (provided in Annex 3) does not exhibit as much of a 'long-tail' associated with potentially substantial, but hard to robustly quantify, benefits not captured by the central assumptions. In addition, unquantified benefits (e.g., the substantial soft-power benefits associated with the international standing of a world-leading Met Office) under this scenario would also be significantly lower.

4.1.1 Central valuations by benefit stream

Table 6 provides the estimated total present benefits, using the central assumptions, for each monetised benefit stream as well as their share in the overall estimated total present benefits.

Table 6 Met Office benefits: Central results by benefit stream

Benefit stream	'Existing' Met Office		'Basic' Met Office	
	Central estimate	% share	Central estimate	% share
Aviation	£12.5bn	22.3%	£5.5bn	22.2%
Climate Adaptation and mitigation	£12.0bn	21.4%	-	-
Value to the Public	£11.6bn	20.7%	£7.4bn	30.0%

[7] In this scenario the Met Office focuses on provision of core meteorological services such as provision of weather information and forecasts to the public, though these would be of a lower quality. Box 3 in Section 3.2 provides further details on this scenario. Further details on the modelling assumptions of this scenario are provided in Annex A2.5.

[8] These are hypothetical reductions in cost. In practice, there would be substantial transitioning costs incurred were the Met Office to transition to a more basic service. These include, for example, redundancy costs and transaction fees for reducing its estates. Crucially, the Met Office's new supercomputing contracts are already predetermined. Therefore, while a more basic service would not need the increased supercomputing capabilities (and thus the modelled hypothetical scenario assumes a lower supercomputing cost, see Annex A2.5), in reality, the costs would still be incurred over the agreed time-horizon and the realised benefit to costs ratio would therefore be substantially lower in the transition period.

Other Business Sectors	£10.9bn	19.4%	£6.9bn	28.0%
Met Office Revenue*	£3.4bn	6.1%	£2.3bn	9.2%
Cold Preventable Deaths	£1.9bn	3.4%	£1.2bn	4.9%
Winter Transport	£1.5bn	2.7%	£1.0bn	3.9%
Flood/Storm Damage Avoided	£0.8bn	1.4%	£0.4bn	1.6%
Space Weather	£0.6bn	1.1%	-	-
International Leadership	£0.4bn	0.7%	-	-
ECMWF	£0.3bn	0.6%	-	-
Heatwave Preventable Deaths	£0.1bn	0.2%	£0.1bn	0.3%
Government Dividends	£0.1bn	0.1%	-	-
Asthma Preventable Deaths	<£0.1bn	<0.1%	<£0.1bn	<0.1%
Commercial Catalytic Benefits	<£0.1bn	<0.1%	-	-
Total Present Benefits	**£56.0bn**	**100%**	**£24.6bn**	**100%**

Note: This analysis provides the central estimated benefits, over the next decade, of the Met Office's activities for each monetised benefit stream. (*) Revenues are excluded in the estimates of the return on public investment as i) commercial contract revenues are a transfer payment from UK businesses to the Met Office and so have a net-zero benefit to the UK taxpayer, and ii) non-commercial Met Office revenue is predominantly public funded and so while it is a benefit to the Met Office it is a cost to the UK taxpayer.

Source: London Economics

Box 5 Public vs. commercially funded benefits

As a trading fund, a portion of the Met Office's revenue—and consequently its impacts—stems from commercially funded work, such as its consultancy activities.

It is not possible to fully disentangle benefits attributable to commercial vs. non-commercially funded activities. The following benefit streams include some aspect of commercial funding in the monetised benefits. An assessment for each benefit stream included in the analysis is provided in Annex A2.6.3.

- Climate research is publicly funded. However, the Met Office also provides climate consultancy services to industry. While these ideally would be disentangled from wider climate adaptation benefits (and counted under benefits to industry) the use of literature estimates on the benefits of better climate adaptation does not make this possible. This is because estimates of improved adaptation include, to some degree, improved adaptation by industry.
- Aviation services are partially funded by commercial revenue from the aviation sector. However, forecast information used in aviation is from the PWS.
- Other business sector benefits capture impacts from provision of weather and climate information through PWS. However, part of the value is also derived through the Met Office's commercial weather and climate consultancy activities.
- The government dividend is a result of Met Office profits as a trading fund. Therefore, part of it is a result of the Met Office's commercial activities.

It should be noted that the Met Office's commercial activities are also reliant on key enabling capabilities such as the Met Office's supercomputer and observations data. These are publicly funded. Benefits resulting from commercial activities / funding would not be deliverable without this public funding in the Met Office's enabling capabilities.

4.2 Evaluation of Met Office costs and revenues

Met Office financial data was used to derive forecasted costs, revenues, and public investments throughout the period of interest (2024-2033).

The following assumptions were also made:

- The Met Office is a Trading Fund. As such, its pricing for goods and services is established to deliver a return on capital to HM Treasury, delivered in the form of a dividend.
- The Met Office receives no recurrent delegated expenditure limit (DEL) or annually managed expenditure (AME) budgets from HM government. All revenue is gained through contracts or contractual-style relationships with public and private bodies, domestically or internationally. As such all revenues are treated as a benefit to the Met Office, not a transfer, even if these have been accrued from government bodies. However, transfer payments were excluded in the evaluation of the return on public investment.
- The Met Office has received a capital grant from the Department for Science, Innovation and Technology of £1,242m to fund the capital investment for the Supercomputer from High Performance Computing (HPC) from 2020-2032, which this study treats as income.
- The costs and revenues used in this analysis are based on the Met Office's Corporate Plan. However, this only extends to 2025/26. Estimates beyond this point are extrapolated assuming a 2% inflation rate[9].

The analysis captures total revenues and total costs with the net difference forming the economic profit which flows through into the final net present value. For the period 2024-2033, **the total present costs** amount to just under **£3.5bn** and the **total present revenues** amount to just over **£3.4bn**[10]. The table below provides a brief overview of the costs and revenues included (please see annex A2.2 for a detailed breakdown of the calculations).[11]

Table 7 Summary of Met Office costs, revenues (2024-2033) under the baseline scenario

Costs	Approach	£-value
Total OPEX (excl. defence)	Includes staff costs and other operating expenditure (e.g. operational supercomputer spend)	£2.5bn
Total CAPEX (excl. supercomputer)	Includes EUMETSAT satellite costs and other day-to-day capital expenditure (e.g. computer hardware, fixtures and fittings)	£0.4bn
Total supercomputing costs	Capital costs associated with the supercomputer, including payments to Microsoft	£1.2bn
Total costs		**£4.0bn**
Total present costs	**Present value calculated using HMT 3.5% discount rate**	**£3.5bn**

Revenues	Approach	£-value

[9] The 2% inflation rate was advised by the Met Office. All costs and revenues beyond 2025/26 are extrapolated assuming a 2% inflation rate, except for PWS revenues which are assumed to remain constant at the 2025/26 level as this is likely to be a maximum point due to specific international costs.

[10] It should be noted that the costs include all expected costs incurred over the period (excluding defence-related costs), particularly future capital expenditures. These costs differ from 'operating costs' typically reported in a profit and loss statement. Unlike operational costs, which tend to follow a consistent trend, capital expenditure occurs in large, infrequent amounts, leading to irregular spending patterns. Consequently, this results in fluctuations in total costs and revenues from year to year, meaning that revenues and costs may not balance precisely within any specific period examined.

[11] Use of the terms 'total costs' and 'total revenues' may not equate to accounting practice but rather treats the Met Office as an economic actor with a requirement to deliver normal profit as part of its standard operation; normal profit is taken to mean 3.5% return on capital.

PWS funding	Payments received under the Public Weather Service (PWS) contract from DSIT	£1.7bn
Other public funding (excl. defence)	Non-PWS and non-Defence payments received via contracts with public sector clients	£0.4bn
Commercial contract revenue	Payments received via contracts with commercial clients	£0.4bn
Other revenue	Payments received through smaller contracts	£0.3bn
Supercomputer funding	Total grant funding received for the new supercomputer	£1.2bn
Total revenue		**£4.0bn**
Total present revenue	**Present value calculated using HMT 3.5% discount rate**	**£3.4bn**

Source: London Economics analysis of Met Office costs/revenue data (components may not sum exactly due to rounding)

Total public investment (used in the calculation of the public return) refers only to funding provided by government departments (thus excluding commercial contract and other revenue). Public investment in the Met Office was estimated based on revenue by funder, with funding from DSIT, FCDO, Defra and the supercomputing operating grant being summed to find total public investment. Data for these components was also provided up to the 2025/26 financial year. The same 2% inflation was applied to funding from FCDO and Defra, whilst funding from DSIT and the supercomputing grant was kept constant at 2025/26 levels. The total present value of public investment was found to be **£2.8bn**.

Costs under the 'Basic' Met Office counterfactual scenario, where the Met Office provides only a basic meteorological service, are assumed to be reduced. This scenario assumes a large reduction (60%) in supercomputing costs, a relatively large reduction (40%) in staff costs, and smaller reductions in other OPEX/CAPEX (5%) and observations (also 5%) costs.

Applying these reductions to baseline costs results in total present costs under this scenario of **£2.3bn**[12]. Public investment is assumed to be the same as costs in this scenario, as there is no commercial revenue in this scenario. Further detail on this scenario, including details on the rationale for these assumptions, is provided in Annex A2.5.

5 Assessment of magnitude of estimated benefits

This section provides a discussion and assessment of the magnitude of the central benefit estimations under the 'Existing' Met Office baseline scenario. It presents the results of the sensitivity analysis and compares estimated baseline benefits to the previous 2015 General Review (London Economics, 2015) and other economic assessments of meteorological services.

5.1 Sensitivity analysis under 'Existing' Met Office baseline scenario

This section provides an analysis of the sensitivities around the central monetised impacts presented in the previous sections. These sensitivities are the results of Monte-Carlo simulations (n=10,000 simulations) around all assumptions used in the modelling of benefits[13]. In addition to uncertainty

[12] These are hypothetical reductions in cost. In practice, there would be substantial transitioning costs incurred were the Met Office to transition to a more basic service. These include, for example, redundancy costs and transaction fees for reducing its estates. Crucially, the Met Office's new supercomputing contracts are already predetermined. Therefore, while a more basic service would not need the increased supercomputing capabilities (and thus the modelled hypothetical scenario assumes a lower supercomputing cost, see Annex A2.5), in reality, the costs would still be incurred over the agreed time-horizon and the realised benefit to costs ratio would therefore be substantially lower in the transition period.

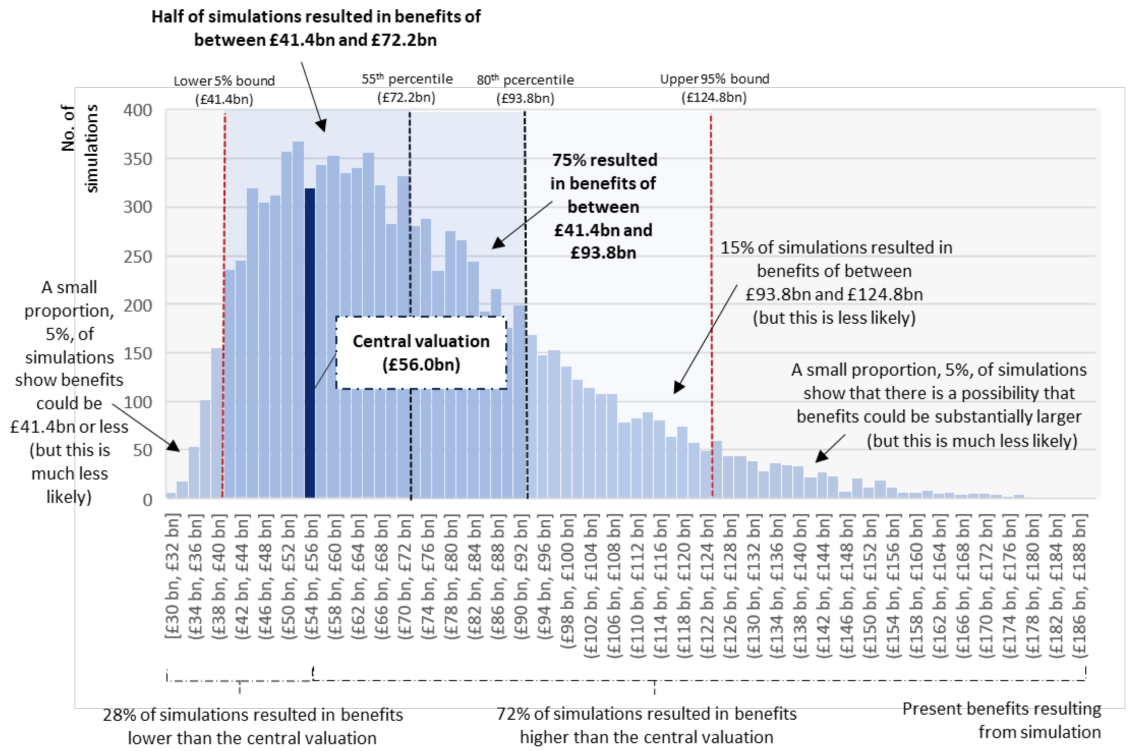
[13] Where sufficient evidence to inform a credible range around assumptions was available, this range was used. Where no evidence was available, the analysis assumed, depending on the judged level of uncertainty, either a ±5% or a ±50% range around central assumptions.

around the assumptions for each benefit stream, the sensitivity analysis also captures uncertainty around future improvements in quality and resulting benefits (see Box 6 at the end of this section).

The results of the sensitivity analysis suggest that:

- The mass of the distribution is concentrated around the central estimates: Half of simulations resulted in benefits of between £41.4bn and £72.2bn, while 75% of simulations resulted in benefits of between £41.4bn and £93.8bn. **This suggests benefits are likely to fall within this range and provides confidence in the central estimates.**
- They also make clear the considerable uncertainty around the central results. Specifically, the long right-tail (i.e., the number of simulations resulting in benefits that are much larger than the central valuations) suggests it is possible (but less likely) that benefits could be substantially larger. In contrast, the comparatively much shorter left-tail (i.e., the number of simulations resulting in benefits much lower than the central valuations) suggests the downside to benefits is much more limited. **This provides evidence that the estimated benefits are more likely to be conservative than an overestimate.**

Figure 3 Sensitivity analysis results - estimated total present benefits (baseline scenario)



Note: The graph shows the results of Monte-Carlo simulations around the total estimated present benefits to the UK, over the next decade, associated with the Met Office's activities. The graph is based on 10,000 simulations. The central results presented earlier would fall within the dark blue shaded bar. The red- and black-dashed lines show the 5th, 55th, 80th, and 95th percentile estimates from the simulations. The percentiles show that i% of simulations resulted in benefits less than or equal to those indicated by the ith percentile. The blue shaded areas between the percentiles indicate ranges within benefits fall – 50% of simulations resulted in benefits between the 5th (lower 5% bound) and 55th percentile, 75% of simulations resulted in benefits between the 5th and 80th percentile, and 90% of simulations resulted in benefits between the 5th and 95th (upper 95% bound) percentiles. 5% of simulations resulted in benefits lower or higher than the lower 5th and upper 95th percentiles, respectively.

Source: London Economics

In these cases, a triangular or truncated normal distribution was used to model uncertainty, reflecting the fact that only very limited information on the minimum, maximum and midpoint of the range were known. In some cases, where central assumptions were very likely underestimates, the lower bound of the sensitivity range was constrained the central estimate. For other business benefits the uncertainty assumptions provided in Ross (2019a) were used, which assumed a normal distribution.

It is also important to note that the sensitivity analysis only captures uncertainties around impacts that have been monetised in this study. In addition to the modelled uncertainties, there are potentially substantial non-monetised benefits which have not been quantitatively evaluated for this study and are therefore not captured in the sensitivity analysis. Unquantified benefits are outlined in Box 2 in Section 4.1.

Together, this suggests that the **central estimates presented in this study are likely to be on the conservative side.**

Sensitivity results for the 'Basic' Met Office counterfactual are provided in Annex 3. Due to the reduced service provided, the sensitivity analysis suggests a narrower plausible uncertainty range.

Box 6 Future changes in quality - uncertainty

There are a range of uncertainties surrounding future growth in quality and therefore benefits.

One particular factor to note is the upcoming shift in the Met Office's supercomputing capacity, which will in future operate as an outsourced capability operated globally by Microsoft (the supercomputer is currently an in-house capability operated on Met Office premises). This entails a substantial increase in supercomputing investments from around £97 million across a six-year period under the previous contract to a total cost of around £1,240 million over a ten-year funding period.

Another factor that could have significant impacts on weather prediction is artificial intelligence (AI). The type and magnitude of impact AI will have is currently unclear. AI could bring substantial cost reductions (following big initial investments), it could deliver accuracy improvements, and/or it could help with targeting and reaching specific user groups. While the impacts are currently unclear, the speed of change of AI means it is likely there will be some impacts.

Further, there are a range of other changes that could drive benefits to grow faster than assumed in the central case. These include new unquantified activities such as the ESA Vigil Mission to launch Europe's first operational space weather spacecraft, as well as the increased focus on improving awareness, understanding and effectiveness of use of Met Office information.

The central benefit valuations presented in the Section 4.1.1 account for some growth in quality. For example, quality improvements could be driven by the regular cycle of supercomputer upgrades, but also improvements in the science and other factors. To account for these improvements, benefits in future years are uplifted by observed growth in quality of Met Office forecasts (described further in Annex A2.4). Concretely, the central estimate assumes that future growth in quality will be similar to that observed over the last decade.

However, the substantial investment in supercomputing capability, uptake of AI, or other drivers could enable benefits to grow faster than historically observed by enabling greater quality improvements than previous upgrades. In addition to quality the new supercomputer could allow modelling for higher geographical granularities or provide additional computing capacity to enable new science to be operationalised. If the new supercomputing capability, investment in AI or other driver indeed unlocks increased quality improvements, the central estimates presented would therefore be an underestimate of the true value delivered by the Met Office over the period examined (2024-2033) and beyond.

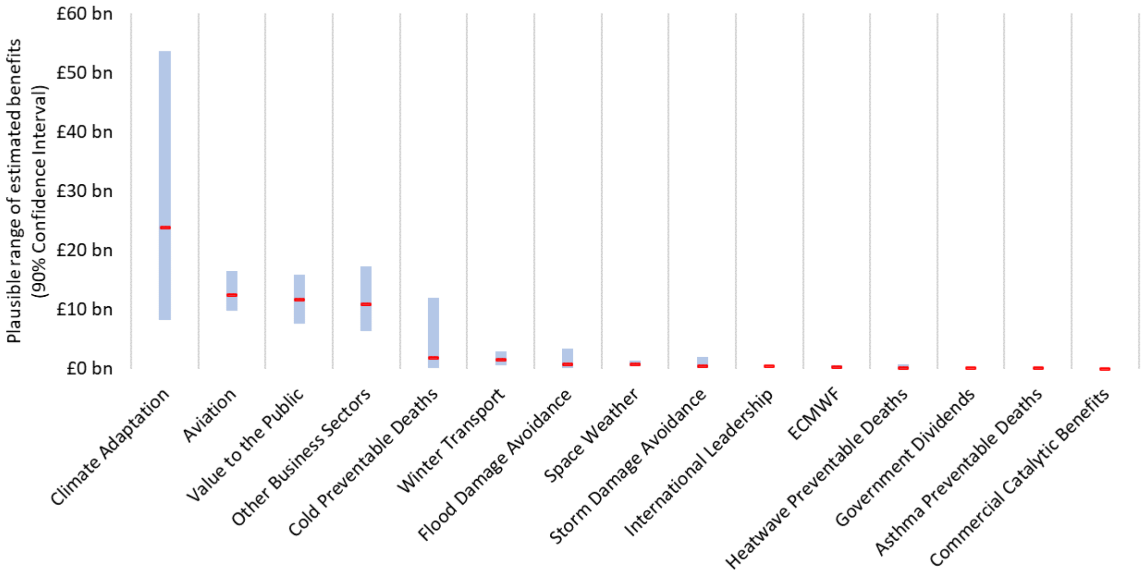
At the same time, quality improvements may be slower than indicated by historic quality improvements. For example, this could be because current forecast accuracy is already so good that future improvements would make a smaller difference and therefore historic growth will be harder to replicate (i.e., there diminishing returns to effort/investment). It should also be noted that delivery of the new supercomputing capability is late, which will have some impact on future benefits or at the very least timing of benefits.

Given the large uncertainty around these effects, modelling these potential impacts is very difficult. Nevertheless, to at least nominally account for some of this uncertainty, the sensitivity analysis assumes a 50% uncertainty interval around the central growth assumptions made.

5.1.1 Drivers of uncertainty surrounding benefit estimates

Figure 4 highlights the uncertainty surrounding each benefit stream under the 'Existing' Met Office baseline scenario. It shows, for each benefit stream under the baseline scenario, the median[14] (red dash) and the plausible range of benefits (90% confidence interval) across all simulations undertaken for the sensitivity analysis.

Figure 4 Sensitivity analysis results – magnitude of uncertainty around benefit streams (baseline scenario)



Note: The graph shows, for each benefit stream under the 'Existing' Met Office baseline scenario, the median (red dash) and 90% confidence interval across all simulations undertaken.

Source: London Economics

This analysis shows that the uncertainty surrounding estimates **of climate benefits are a substantial driver of the uncertainty around estimated benefits**, accounting for more than half (55%) of the uncertainty in total benefits. This variation is driven by the complexity of estimating the magnitude of benefits of mitigation and adaptation measures to reduce the impact of climate change. As a

[14] The median is typically used instead of the mean as it is less skewed by outliers. Examining the median alongside the uncertainty range can be helpful to understand the shape of the distribution. If the median is in the middle of the range this suggests the implied distribution is more symmetrical. Conversely, if the median is closer to one end of the range, this indicates a skewed distribution, implying there could be significant outliers or a potential for large values on one side with a relatively lower probability.

result of this literature estimates of benefits, which underly the estimation of climate benefits, vary widely (see Annex A2.1.3).

The little remaining uncertainty is a composite of the uncertainty surrounding key benefit streams including cold preventable deaths (accounting for 15% of the variation), benefits to industry (13%) and the public (10%), and aviation benefits (8%).

Further details on the sensitivity analysis for individual benefit streams, including boxplots providing a more nuanced visual examination of the uncertainty for each benefit stream, are provided in Annex 3.

Box 7 Potential ongoing impact of COVID-19 - uncertainty

It is possible that lingering effects of the Coronavirus pandemic have had an impact on the level and/or future trajectory of benefits. Societal shifts stemming from the pandemic could impact benefits in a multitude of ways. For example, changes in travel volumes and patterns could impact aviation benefits, changes in the ways of working could impact the weather sensitivity of business sectors, and thereby benefits, etc. While exploring the potential impacts of COVID-19 in detail was beyond the scope of this study, it is nevertheless important to acknowledge them. In most cases the impact of COVID-19 was not modelled directly in this study. Nevertheless, the sensitivity analysis allows for, and models the impact of, uncertainty around all assumptions made. It further allows for uncertainty around the future trajectory of benefits (see Box 6). Therefore, while COVID-19 impacts are not modelled directly, the analysis nevertheless allows for some degree of uncertainty, such as that stemming from ongoing COVID-19 impacts. The potential impact of COVID-19 on all benefit streams is discussed further in Annex A2.6.4.

5.2 Comparison to previous General Review

Baseline benefits in the previous 2015 General Review were estimated at £$_{2015}$31.8bn in 2015 prices. This is equivalent to £$_{2024}$40.0bn in 2024-pound terms[15]. The central estimate of total present benefits under the baseline scenario in the current study is £$_{2024}$56.0bn, an increase of £$_{2024}$16.0bn or 40%.

The central benefit-to-cost ratio (16.1) and public-benefit-to-public-cost (18.8) in this study are slightly higher than the central benefit-to-cost ratio in the 2015 evaluation (14.1). This is due to an increase in service provision and the measurement of associated benefits, such as with space weather. As well as a change in approach to estimating some benefit streams. In terms of costs, the costs in the previous study were estimated to be lower with an estimate, in 2024-price equivalent, of £$_{2024}$2.8bn (£$_{2015}$2.3bn in 2015 prices). In comparison, in this study, costs were estimated to be in the region of £$_{2024}$3.5bn. Public investments in the Met Office are estimated at £$_{2024}$2.8bn.

The higher costs in this study are predominantly driven by increased staff costs and higher supercomputing investments. While these higher inputs are an increased cost to the Met Office, they in turn may also enable the Met Office to further improve its offering and thereby drive higher benefits. However, without robust evidence of the magnitude of these increased benefits, the central valuations have again taken a conservative approach (see discussion in Box 6).

[15] Deflated using OBR/ONS GDP deflators.

The face-value comparison also masks several other important factors that need to be considered when comparing the headline results of the two studies:

- An extensive literature review was undertaken to evaluate and update the robustness of the evaluation of each benefit stream. As a result of this review the evaluation approaches used in this study were updated and new evidence was incorporated where available (see methodological annex). However, in a number of cases, the results of this review also identified a lack of new and/or more robust evidence suggesting that the approaches and assumptions used in the previous study are still the most robust evidence available.
- Nevertheless, in some cases, the best available quantitative evidence now dates back many years. As result, some assumptions could now be underestimates. Qualitative evidence suggested that this is indeed the case for some assumptions[16]. However, in the absence of new robust quantitative evidence, the analysis erred on the side of caution and used the previous assumption as the most robust evidence available. In these instances, potential improvements have instead been accounted for through the sensitivity analysis. The discussions on the evaluation of individual benefit streams, and the methodological annexes, provide further details.
- There are also some important methodological differences compared to the previous 2015 General Review that impact the level of benefits in this study. These are discussed further alongside the evaluation results of benefits and in the methodological annex to this study. Box 8 provides a summary of the most important differences.
- There are a range of potential factors that may lead to larger future benefits than assumed in the central case. These are discussed further in Box 6. They include a shift in the level of investment in supercomputing, new unquantified activities such as the ESA Vigil Mission, and the increased focus on ensuring Met Office forecasts not only become qualitatively better but are also seen, understood, and acted upon by the widest possible audience. This may mean benefits grow faster than assumed in the central case.

Therefore, the central valuations presented in this study should be interpreted as conservative estimates. Indeed, the results of the sensitivity analysis highlight the substantial uncertainty around the magnitude of benefits. The 90% confidence intervals from the sensitivity analysis indicate that total present benefits could plausibly be substantially larger than implied by the central valuations.

Box 8 Key methodological differences, to the previous 2015 General Review, in the evaluation of individual benefit streams that impact the magnitude of total benefits

There are several important methodological differences in the evaluation of individual benefit streams compared to the previous 2015 General Review. Key differences and the direction of impact on the level of total present benefits in this study are highlighted below. The methodological annex to this study provides further details on the updated evaluation methodologies for all benefit streams.

Benefit stream	Methodological change	Direction of impact
Value to the public	Previous literature estimates were outdated and did not specifically capture the UK context. New primary research focused on the value the Met Office	↑

[16] For example, anecdotal evidence suggests that the quality of storm/flood warnings improves by around one-day a decade. However, no new quantitative evidence on the proportion of storm/flood damages avoided was identified in the literature. It is therefore likely that the proportion of flood/storm damage avoided is now higher than ten-years ago.

	brings to the UK public suggests the value to the public is around double that implied by previous literature estimates (£21.33 per adult vs. £9.18-£12.03 in 2024 prices). This means estimated benefits are around £5bn higher than estimates in the previous 2015 General Review (£11.6bn vs. £6.5bn in 2024 prices).	
Climate adaptation	Climate benefits were updated based on a review of the wider and recently emerged climate literature and the evaluation approach was updated. The results suggest climate adaption and mitigation benefits attributable to Met Office research are likely substantially larger than previously assumed. The previous 2015 review estimated climate benefits to be in the region of £3.2bn. This is equivalent to approximately £4.0bn in 2024-£ terms. Research undertaken for a separate evaluation study of the benefits of the Met Office Hadley Centre Climate Programme suggest benefits are more likely to be in the region of between £6.4bn and £94.4bn. The central estimate used in the present study is £12bn. This is an increase of around £8.0bn compared to estimated benefits in the 2015 General Review.	↑
Cold preventable deaths	New literature suggests the assumption on the share of cold avoidable deaths used in the previous 2015 study was a substantial underestimate. As a result, estimates of cold preventable deaths have increased from low levels in the 2015 study to around £1.9bn in this study. The updated methodology used in this study is consistent with that used in the previous, more recent, socio-economic benefits evaluation of the Met Office's heatwave and cold weather (London Economics, 2019).	↑
Space weather benefits	Space weather benefits were not included in the previous valuation. This study incorporates new estimates of expected damages avoided, attributable to the Met Office, from space weather events to the UK electricity grid. These additional benefits are estimated at around £0.6bn.	↑
Industry benefits	The evaluation approach for industry benefits not evaluated separately (i.e., 'other industry benefits') has evolved. The new methodology improves upon the previously used methodology by taking into account awareness and behavioural factors. Following the same approach as the previous study, benefits to industry would be about £2.1bn higher in this period compared to the previous estimate in 2024 prices. However, estimated benefits using the new approach are lower, by around £1.1bn, than the previous estimate inflated to 2024 prices (see Box 18 in Section 8.1).	↓
Defence benefits	The previous study included defence benefits. Defence benefits/costs are out of scope of the current study. Defence benefits were estimated at around £1.4bn in the 2015 General Review. This is equivalent to approximately £1.8bn in 2024 pound-terms.	↓
Flood / storm damage avoided	The benefits of flood damage avoided attributable to the Met Office were previously estimated at £0.67bn (equivalent to £0.84bn in 2024 prices). The best available evidence today suggests that benefits are lower in the region of £0.44bn. This is because estimates of the average annual flood damage in recent studies are lower than those in older studies (see discussion alongside evaluation results in Section 6.2.1). Similarly, methodological changes on the attribution of storm damages mean that attributed damages in this study are lower than previously at £0.32bn vs. £0.62bn estimated in the previous 2015 General review (equivalent to £0.78bn in 2024 prices).	↓
RIMNET	RIMNET was replaced by RREMS which no longer sits within the Met Office. Therefore, benefits for RREMS were not monetised in this study. However, the magnitude of the reduction is comparatively small at around £0.01bn.	↓

5.3 Comparison to other economic assessments of met services

Table 8 presents a number of studies which have established benefit-to-cost ratios for meteorological services in other countries, providing context for the results of this study. Some of the information is drawn from an unpublished summary of economic assessments of meteorological services around the world, provided by Jeff Lazo during the 2015 General Review.

The majority of benefit-to-cost ratios lie between 2:1 and 14:1. The benefit-to-cost ratio calculated in this study, 16.1:1, is higher than most of the comparative studies. This difference is likely driven by the wider range of services provided by the Met Office. In comparison, a number of the studies focus on specific sectors or benefits, which would not be expected to deliver benefit-to-cost ratios as high as the entire Met Office services.

Table 8 International benefit-cost ratios

Study	Geographic Location	Sectors	Benefits Methods/ Measures	Benefit-to-cost ratio
Contingent Valuation Study of the Public Weather Service in the Sydney Metropolitan Area (Anaman and Lellyett, 1996)	Sydney, Australia	Households	Willingness-to-pay (WTP) survey of households	4:1
Economic Value of Current and Improved Weather Forecasts in the U.S. Household Sector (Lazo and Chestnut, 2002)	United States	Households	Willingness-to-pay (WTP) survey of households	4:1 +
Benefits of Ethiopia's LEAP Drought Early-Warning and Response System (Law, 2012)	Ethiopia	Households	Quantification of avoided livelihood losses and decreased assistance costs	3:1 to 6:1
Success of the NWS's Heat Watch Warning System in Philadelphia (Ebi et al., 2004) system	Philadelphia, Pennsylvania	Households/ elderly	Regression analysis to determine lives saved; application of the U.S. EPA's Value of a Statistical Life estimate	2,000:1 [17]
The Benefits to Mexican Agriculture of an El-Nino-southern oscillation (ENSO) Early Warning System (Adams et al., 2003)	5-state region in Mexico	Agriculture	Change in social welfare based on increased crop production with use of improved information	2:1 to 9:1
The Value of Hurricane Forecasts to Oil and Gas Producers in the Gulf of Mexico (Considine et al., 2004)	Gulf of Mexico	Oil drilling	Value of avoided evacuation costs and reduced foregone drilling time	2:1 to 3:1
Economic Efficiency of NMHS Modernization in Europe and Central Asia (World Bank, 2008)	11 European and Central Asian countries	Weather-dependent sectors	Sector-specific and benchmarking approaches to estimate avoided losses	2:1 to 14:1
Benefits and Costs of Improving Met-Hydro Services in Developing Countries (Hallegatte, 2012)	Developing countries	National level and weather-sensitive sectors	Benefits-transfer approach to quantify avoided asset losses, lives saved, and total value added in weather-sensitive sectors	4:1 to 36:1

[17] The benefit-to-cost ratio for this study is an outlier, with an estimate above 2000:1. This is because the approximate cost of the heat warning system was relatively low, around $210,000 across the three-year period, and the estimated benefit was relatively high, approximately $468m over the same period. The benefit estimation is based on 117 lives being saved, with each life valued at $4m.

Study	Geographic Location	Sectors	Benefits Methods/ Measures	Benefit-to-cost ratio
Avoided Costs of the FMI's Met-Hydro Services Across Economic Sectors (Leviakangas and Hautala, 2009)	Finland	Key economic sectors	Quantification of avoided costs and productivity gains; Also used impact models and expert elicitation	5:1 to 10:1
Social Economic Benefits of Enhanced Weather Services in Nepal – part of the Finnish Nepalese Project (Perrels, 2011)	Nepal	Agriculture, transport, and hydropower		10:1
Economic and Social Benefits of Meteorology and Climatology	Switzerland	Transport, energy, aviation, agriculture, households	Benefits transfer, expert elicitation, decision modelling	5:1 to 10:1
Socio-Economic Study on Improved Hydro-Meteorological Services in the Kingdom of Bhutan (Pili-Sihvola et al., 2014)	Bhutan	National level	Benefits transfer, expert elicitation, cardinal rating method	3:1
Study of the economic impact of the services provided by the Bureau of Meteorology (London Economics, 2017)	Australia	Agriculture, households, aviation, economic sectors	Quantification of avoided costs	11.6:1
Benefits of economic assessment of cyclone early warning systems - A case study on Cyclone Evan in Samoa (2019)	Samoa	Weather-dependent sectors, households	Quantification of avoided costs and productivity gains	1.72:1 to 1.92:1
Valuing deaths or years of life lost? Economic benefits of avoided mortality from early heat warning systems (2018)	Spain	Households	Lives saved	21:1 to 3700:1

Source: Some reports from unpublished USAID/World Bank/WMO analysis, provided by Jeff Lazo

PART III: DETAILS ON KEY MET OFFICE ACTIVITIES AND RESULTING BENEFITS

This part provides:

- **Qualitative discussions** on activities, and resulting benefits, for the key Met Office activity groupings used in this study. The groupings follow the **activity groupings** developed in the Theory of Change in Part I of this study.
  - Weather services (Section 6)
  - Climate services (Section 7)
  - Benefits to industry (Section 8)
  - Scientific, innovation and technology-related activities (Section 9)
  - Other key activities (Section 10)
- The '**pathways to impact**' **for key activities** highlighting the inputs, activities, outputs, outcomes, and impacts – presented as figures alongside the qualitative discussion in each chapter.
- **Further discussions on the valuation of key benefit streams** that fed into the total aggregate benefits in Part II are presented in boxes throughout the following chapters.

Image credit: Steven Wright/unsplash

6 Weather services

As the UK's national weather service, a key function of the Met Office is the provision of weather information and data to the public, government and industry. Accurate, timely and easy-to-digest weather information helps individuals and organisations make better decisions in their daily lives. This starts with very simple decisions such as whether to take an umbrella or put on a raincoat when leaving the house, whether to choose indoor or outdoor activities, and helping individuals make better plans for important events such as weddings or funerals, or outdoor gatherings.

High quality weather information also plays a key role in many decisions made by industry. For example, a farmer may use weather information to make decisions about when to plant or harvest crops. The construction sector might need to decide when to undertake construction on a building. Event organisers might need to make decisions about whether to cancel or reschedule events such as sporting events or other large outdoor gatherings.

In addition to weather information the Met Office provides a wide range of additional weather-related services. This includes the National Severe Weather Warning Service, which provides advanced warning for heavy rain, strong winds, snow/ice and high temperatures.

These warnings provide crucial input to severe weather warnings provided by other public bodies such as flood warnings issued by the Flood Forecasting Centre, a partnership between the Environment Agency and the Met Office, and the Heat-health Alert service provided by the UK Health Security Agency in partnership with the Met Office.

Weather-related services also include the Met Office's work in supporting the UK civil contingencies community, the provision of specialist forecasts such as pollen or UV levels, and other weather-related services such as bespoke forecasts and advice to government and industry. One important example of this is the provision of bespoke forecasts, analysis, and advice to support the government's energy security priorities.

The following sections explore the benefits of weather information (Section 6.1), focused on provision of weather information to the general public, extreme weather alerts (Section 6.2), and specialist forecasts (Section 6.3). Benefits to industry are presented in Section 8.

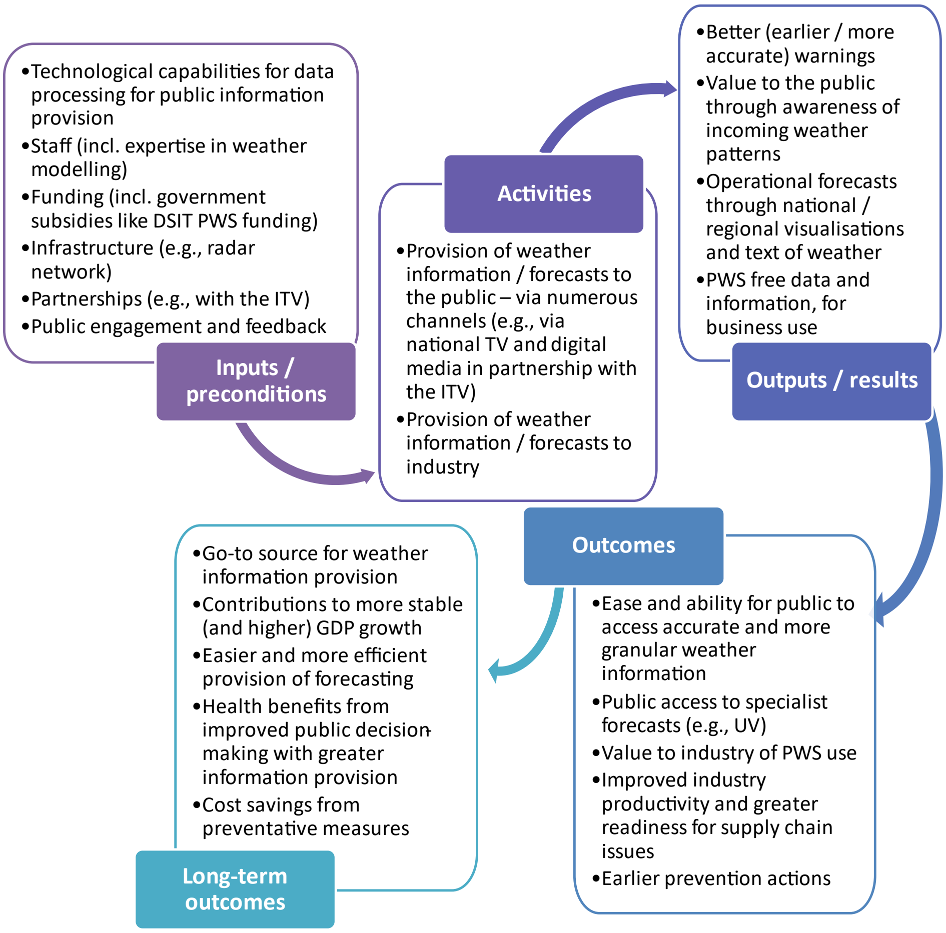
6.1 Provision of weather information

One of the main objectives of the Met Office's weather services is to provide easily accessible and accurate weather forecasts and weather information. These accurate and readily available weather forecasts empower the public to make informed decisions about their day-to-day activities. They also help businesses plan their operations and resourcing. Figure 5 shows the impact pathway associated with the provision of weather information. This explores key inputs, activities, and the resulting outputs and outcomes of these activities in further detail.

Key inputs include the technological infrastructure and capabilities of the Met Office, which underpin all the services the Met Office provides. This includes capabilities partly funded by the Public Weather Service (PWS), e.g., observation data and the Met Office's computing capability, and data post-processing and modelling. It also includes a range of other important inputs and enabling activities such as expert meteorological staff and scientific partnerships, among many others. The Public Weather Service Customer Group (PWSCG) is responsible for overseeing the PWS on behalf of government and the public sector. Delivery of the PWS is mainly funded by the Department for Science Innovation and Technology (DSIT).

The Met Office disseminates weather forecasts and information through various channels. This includes direct channels such as the Met Office's online web services, mobile app, reports, and data provision. Met Office weather information is further disseminated through a number of indirect channels. This includes television channels, radio, the internet and mobile apps from other providers. For example, the Public Weather Media Service (PWMS) provides a package of Met Office public weather service information (forecasts, weather warnings, observations, guidance, scripts and services) to a range of UK Broadcasters. Met Office information and data are also used by third-party providers as inputs to their own products and services (e.g., third-party weather forecasts, specialist forecasts). Thus, Met Office services and products stimulate the private weather market and further increase the reach of Met Office information.

Figure 5 Impact pathway: Provision of weather information



Source London Economics

Outputs and outcomes of the Met Office's provision of weather information are far reaching and include a multitude of micro decisions by the public, industry, and other actors such as local first responders. While it is impossible to provide a comprehensive list of all the decisions informed by weather information, examples of how people use weather information in their daily lives are provided in Box 9. Examples of instances where industry and other organisations may use weather information to inform decisions are presented in Box 17 in the section on benefits to industry (Section 8).

Box 9 Examples of micro-decisions made by the public based on weather information

Decisions related to <u>health and safety</u> and to <u>protect property</u>:

- Decisions about when to take medication for a health condition that is affected by the weather
- Changing plans because a member of the public or someone they care for, have/has a health condition that is affected by the weather
- Buying flood protection products, or sandbagging the property
- Taking shelter from the sun or heat, salting, or clearing paths/drive, and securing things around the property
- Stocking up on food, shopping early, or thinking through/preparing a food plan

Decisions related to <u>community</u>, and <u>getting/providing information about the weather</u>:

- Signing up for flood warnings direct, finding out if home is at risk of flooding
- Informing friends/family/neighbours or someone else about it
- Checking that friends/family/neighbours are safe, helping/supporting someone else
- Joining a community group

Actions in relation to <u>work and travel</u>:

- Driving more safely/slowly
- Not drive at all, or walking everywhere
- Changing travel plans, or plans for long distance travel (including by train/plane)
- Staying at home, avoiding working outside
- Leaving work early, or altering my work plans

Other activities, daily tasks, and plans that might be affected by the weather:

- Changing plans for undertaking an activity in a risky setting (e.g., mountains/coastal areas)
- Cancelling a planned activity, or planning a different activity to be inside
- Taking an umbrella or wearing different clothes
- Applying sunscreen, carrying water
- Decided whether to hang out washing
- Deciding to put the heating on

Each of these micro-decisions is associated with a benefit, with the sum of all these benefits providing the overall economic impact associated with the provision of weather information. However, due to the large number and variety of potential decisions made, an evaluation of the impact of each of these micro decisions is not feasible. This is a common issue with bottom-up valuation approaches. In cases where a bottom-up evaluation is deemed as too complex, alternative approaches such as contingent valuations and discrete choice experiments are often used.

In this study, benefits resulting from the Met Office's provision of weather information are evaluated through examining the following benefit streams:

1) The value the public derives from Met Office provided weather information, evaluated using the above-mentioned contingent valuation method (described below), and

2) Benefits to industry users, based on an aggregate valuation using literature assumptions of the weather sensitivity of different industries combined with behavioural and market share assumptions (discussed in Section 8).

Box 10 Evaluation of the value of weather information to the public (baseline scenario)

Approach: For this study, the value to the public was estimated by conducting a willingness-to-pay (WTP) survey. The survey employed non-market valuation techniques to estimate the value of the Met Office PWS to the public. The survey gathered responses from a representative sample of 1,002 UK adults. The fieldwork was conducted by YouGov between 26th January and 2nd February 2024.

The key elements of the survey comprised of stated preference valuation questions, including a contingent valuation and discrete choice experiment. Specifically, the contingent valuation was used to estimate the overall value of the Met Office PWS to the public. This method aimed to ascertain the average amount individuals who would be willing to pay annually in order to maintain the existing Met Office PWS, compared to a situation where the Met Office would no longer provide the PWS. Please see annex A2.1.1 for further details on the methodology.

Alongside these questions, the survey also explored topics such as usage of weather forecasts, trust in weather forecasts, actions taken in response to weather forecasts, and awareness and perception of severe weather warnings issued by the Met Office. The complete findings from the survey are detailed in a separate report.

The average annual WTP figure obtained from analysis of the contingent valuation was then multiplied by the UK adult population to calculate the total value to the UK public.

Results: The main result of the average WTP for the Met Office PWS was estimated to be between £19.67 and £22.99 per year[18] (with a central estimate of 21.33 per year)**.** By scaling this up for the UK adult population, the central estimate for the value to the public is a present benefit of £11.6bn over 2024-2033. This accounts for 21% of the total present benefits.

This value is higher than in the 2015 General Review (£6.5bn in 2024 prices). This is mainly driven by lower average WTP estimates being used for the value to the public in 2015. The figures used in 2015 were average WTP estimates of between £7.30 and £9.56 per year, based on PA Consulting (2007) and Buchanan (2012), respectively. In 2024 prices these would be equivalent to £9.18 and £12.03. However, these figures cannot be directly compared to the updated figure in this study. The previous estimates were derived from a different methodological approach and did not specifically capture the value of the Met Office PWS, but rather assessed the value of weather forecasts as a whole.

Drivers of the WTP estimate: The other questions included in the survey allowed for an analysis of the average WTP across subgroups of respondents. For example, the findings indicate that a higher valuation for the Met Office PWS was driven by those respondents who were identified as ‘high frequent users’ of weather forecasts. High frequent users in this case were defined as those who look at weather forecasts at least 2 to 3 days a week. Average WTP valuations were also higher for those that said they trust weather forecasts (at least ‘a little’) and amongst those respondents who indicated that they find severe weather warnings (at least ‘fairly’) useful.

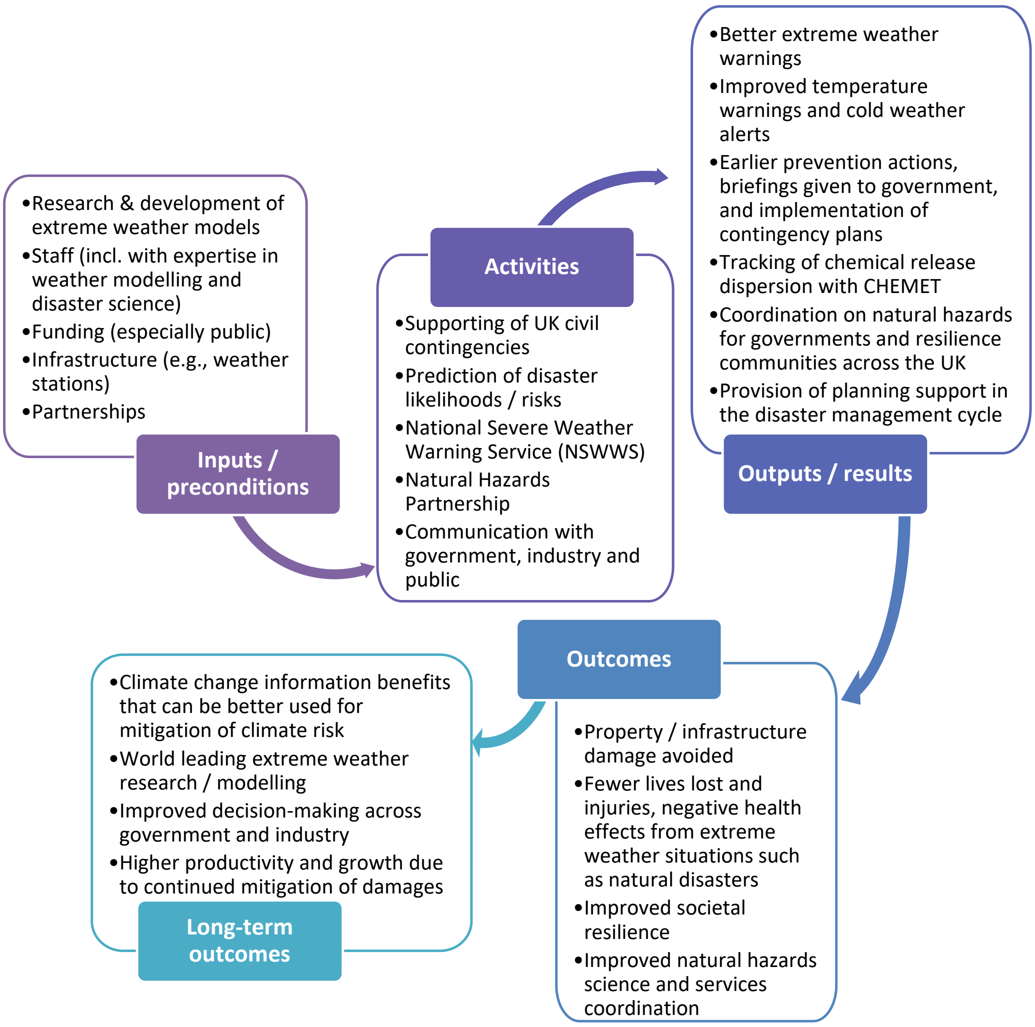
[18] This range is based on the 95% confidence interval.

Younger individuals (aged 18-34) and those from higher socioeconomic groups also have a higher valuation of the PWS compared to the average.

6.2 Extreme weather alerts and civil contingencies

The Met Office issues weather warnings in the UK when extreme weather conditions have the potential to cause adverse impacts. Warning levels are determined based on the potential level of impact and the likelihood of those impacts occurring. The Met Office National Severe Weather Warning Service (NSWWS) issues warnings for various weather events. This includes heavy rain, which provides an input to flood risk warnings issued by the Flood Forecasting Centre (FFC)[19], thunderstorms, extreme temperatures, strong winds, snow, lightning, ice and fog.

Figure 6 Impact pathway: Extreme weather alerts and civil contingencies



Source London Economics

[19] The FFC is a partnership between the Environment Agency, the Met Office, and the Department for Department for Environment, Food & Rural Affairs (DEFRA), which provides a Flood Warning Service.

The Met Office also plays a crucial role in preparing for and mitigating the impacts of weather events and emergencies. This includes direct activities such as alerting people and raising awareness through initiatives such as storm naming[20]. It also includes partnerships such as working with the Environment Agency, local authorities and local responders, civil contingency planners, the police, fire and rescue services, and health services to ensure robust mitigation strategies are in place. The Met Office also provides briefings to top-level government officials including Whitehall, the Cabinet Office and various ministers (e.g., via participation in COBRA meetings) to support the mitigation of extreme weather impacts.

This study estimates the value of Met Office weather warnings for extreme rain (flood damage avoided and lives saved), thunderstorms (storm damage avoided and lives saved) and extreme temperatures (heat/cold related deaths prevented), described further in the following sub-sections.

In addition to providing weather forecasts, the Met Office plays an important role in supporting civil contingencies by providing information and expertise derived from extreme weather models. This information contributes to government risk planning and risk assessment, aiding in preparation for and mitigation of the impacts of extreme weather events. The Met Office also holds responsibility for several risks on the government's National Risk Register (HM government, 2023).

Collaborative partnerships are a key component of how the Met Office communicates its expertise on extreme weather science and facilitates coordination in the UK. These partnerships involve various stakeholders, including government agencies, local communities, emergency services, the health sector, and other public agencies. One example is the Met Office's involvement in the Natural Hazards Partnership (NHP), a consortium of public bodies which provides information, research, and analysis on natural hazards. The NHP's objective is to improve disaster management plans for civil contingencies, government entities and responder communities in the UK.

The benefits of extreme weather alerts include the avoided damage to people and property during extreme weather events. This means reduced economic loss as well as fewer lives lost and reduced negative health and well-being effects.

6.2.1 Flood and storm damage avoided

Flooding is an impact of extreme weather that can cause significant damage to people and property. The Met Office works in collaboration with the Environment Agency (EA), Scottish Environment Protection Agency (SEPA) and Natural Resources Wales (NRW), Department for Infrastructure (Northern Ireland) and other professional experts to forecast floods. In addition, the Met Office, in partnership with the Environment Agency, operates the Flood Forecasting Centre (FFC) which provides, among others, a daily flood risk forecast as well as the Flood Guidance Statement (FGS) showing flood risk for the coming five days. Flood warnings and alerts are then issued by the relevant national body (i.e. EA, SEPA, NRW).

In this study, the value of flood damage prevention is estimated using an **avoided cost approach**. This captures the prevented damage to property from fluvial and coastal flooding. The stream captures the benefits that the public and businesses receive through flood warnings, including being able to protect the property from flooding. It also considers impacts beyond property damage, including the impacts of flooding on health, vehicle damage and emergency services.

[20] Please see: https://www.metoffice.gov.uk/weather/warnings-and-advice/uk-storm-centre/index

A similar methodology to flood damage prevention is adopted to estimate the value of storm damage prevention, whereby an avoided cost approach is used. This captures the prevented damage to property from storms. The stream captures the benefits that the public and businesses receive through storm warnings, including being able to protect the property. As with flooding, the methodology also considers impacts beyond property damage.

Box 11 Evaluation of the value of flood/storm damage avoided (baseline scenario)

Approach: The study used a value chain approach to estimate the benefit of avoided flood damage due to the Met Office's contribution to flood warnings. The approach follows the method used in the 2015 study, however, in this analysis uplifts are applied to the estimate for annual flood damage to account for costs associated with vehicle damage, health and wellbeing, and emergency services. The current approach only considers fluvial and coastal flooding. Further, there are other impacts which are not captured by the uplifts applied; for example, avoided impacts of flooding at chemical plants or nuclear reactors. Additional work (outside the scope of this study) would be needed to account for other types of flooding not currently captured (e.g., surface water flooding).

Similarly, the study also uses a value chain approach to estimate the benefit of avoided storm damage due to the Met Office's contribution to storm warnings. The approach uses a modified method that first estimates the total storm damages occurring in the UK (by scaling European damages by the UK's GDP relative to EU GDP), then calculates the likely share of avoided damages, and finally attributes a share of UK damages avoided to the Met Office. The share of avoided damages attributable to the Met Office is assumed to be similar to that for flooding. Uplifts are again applied to the estimate for annual storm damage to account for costs associated with vehicle damage, health and wellbeing, and emergency services.

In line with the previous study a contribution of the Met Office of 25% to flood damages avoided was assumed. The same assumption is also used to attribute a share of avoided storm damages to the Met Office. This attribution assumption was originally based on estimates from PA (2007) and is now quite old. As such, attribution may again be an area where future primary research, e.g., in the form of case studies, could be beneficial. It is plausible that the Met Office's contribution may have changed in this time, for example, due to the important role the Met Office plays in the in the Flood Forecasting Centre, which is operated in partnership with the Environment Agency, and was established in 2007 (and so would not have been captured in the PA (2007) estimates. While the present study sought to update this assumption, no strong evidence to robustly justify a change to the attribution was identified. Therefore, uncertainties surrounding attribution, and the onward impact on total estimated benefits attributed to the Met Office, were explored in the sensitivity analysis (see discussion in Annex A2.1.1).

Results: The central estimate is a present benefit of around £440 million of flood damages avoided and around £320 million of storm damages avoided over 2024-2033. Together, this accounts for 1.4% of the total present benefits.

For comparison, the previous 2015 General Review estimated flood damage avoided benefits to be at £670 million. The estimate for storm damage avoided benefits was £620 million. This is equivalent to £840 million and £780 million in 2024 prices, respectively. Therefore, the current estimates are lower. The difference is driven by i) a lower figure for annual average flood damages to the UK[21] and ii) the methodological changes to the attribution for storm damages.

These changes were made in light of recent literature evidence (see Annex 2) suggesting lower values for both average annual flood damages as well as uplifts for intangible benefits applied previously. It is possible that these estimates are lower in part due to better prediction and mitigation of flooding events. However, insufficient evidence was available to substantiate a robust assumption quantifying this effect. Further, due to climate change, the incident of flooding and storms may indeed increase further in future, suggesting damages may become larger despite increased mitigations. Nevertheless, consistent with decisions made throughout this study, it was elected to err on the side of caution and use the lower estimates in the central valuation. The central results should therefore be interpreted as a conservative central estimate. Actual avoided flood and storm damages over the next decade may be higher than this central estimate. Further research to explore these methodological challenges and substantiate more robust assumptions would be useful in this area.

Sensitivity around this choice was explored in the sensitivity analysis, which used the higher previous damage figures (in current prices) as the upper bound. The results of this sensitivity analysis show that benefits of avoided flood and storm damages could be substantially larger than the central valuations. The 90% confidence interval of the sensitivity analysis indicates that the benefits of flood and storm damages avoided could plausibly be up to £5.4bn combined, more than three times larger than the estimates from the previous 2015 General Review. However, the results of the analysis show that very large values are much less likely. Indeed, 75% of simulations resulted in benefits of up to £2.5bn, suggesting this is a more likely range. The sensitivity analysis results for flood and storm damages avoided are provided in Box 26 in A2.1.1.

6.2.2 Extreme temperature

Prolonged periods of extreme temperature (i.e., heatwaves or cold weather) can have negative health effects. Extreme weather modelling plays an important role in England's Adverse Weather and Health Plan. This outlines the recommended actions for various stakeholders, including local government, the NHS, UK Health Security Agency (UKHSA), and other entities within the healthcare sector. The Plan's primary objective is to mitigate the health impacts associated with extreme temperatures. One of the key health benefits of this plan is the lives saved through advanced warnings of prolonged periods of extreme temperatures.

The Heat-Health alert service, provided by UKHSA in partnership with the Met Office operates between June and September. This service aims to assist healthcare professionals in managing situations of extreme temperatures effectively. In 2023, the Heat-Health alert service underwent an update and brought it in closer alignment with the NSWWS.

The new service is based on an impact-based system meaning that an alert is not automatically triggered when the temperature threshold is forecast to be breached. Rather, the new system takes into account many contextual factors beyond temperature (e.g., hospital admission data), triggering an alert only if the threshold is forecast to be breached *and* UKHSA and the Met Office agree that an alert should be issued given the likely impact resulting from the event.

[21] The 2015 General Review used an estimate of £3.2bn for flood damages avoided, whereas this study uses an estimate of around £935 million (see Annex A.1 for further details).

Box 12 Evaluation of the value of lives saved from extreme temperature alerts (baseline scenario)

Approach: This study uses an approach developed by London Economics (2019) which estimated the socio-economic benefits of the UKHSA health alerts issued in partnership with the Met Office. The approach estimates the number and monetary value of avoided deaths due to the Met Office's contribution to extreme temperature alerts. This updated approach builds on the method used in the 2015 General Review by applying more robust assumptions based on more recent literature. This approach also distinguishes between premature deaths (deaths of otherwise healthy individuals) and displaced deaths (deaths of individuals who would have died relatively soon independent of external causes), which allow for a more accurate evaluation of the value of lives saved.

The move to an impact-based system means there are likely to be fewer alerts issued and therefore associated benefits on days where no impact is issued under the new system (but would have been under the old system) may be lost. However, the assessed benefits of the value of heat/cold-weather related deaths avoided are likely to disproportionately stem from more severe events, such as where very hot or cold temperatures are combined with other factors such as existing pressures on the health-care system that in combination lead to excess mortality. As such, the associated impact on total benefits is judged to likely be relatively small. Further, impact-based alerts may also lead to behavioural changes resulting in vulnerable groups to be more likely to take mitigation actions than under the old system where alerts were issued for any forecast breaches of temperature thresholds. Therefore, no further adjustment was made to the central estimation of the benefit stream, though the sensitivity analysis undertaken allows for a reduction in the number of deaths avoided.

Results: The central results estimate a present benefit of £1.9bn (from 2024-2033) for the value of avoided deaths due to cold weather alerts, and around £110 million for the value of avoided deaths due to heatwave alerts. This accounts for 3.4% and 0.2% of the total present benefit, respectively.

The benefits associated with the Met Office's cold weather warnings are considerably larger compared to the benefits associated with the heatwave warnings because of a higher number of cold-related deaths and the high share of premature (as opposed to displaced)[22] mortality induced by cold weather.

6.3 Specialist forecasts

The Met Office offers a number of specialist forecasts. These provide benefits for people with specific needs (e.g., respiratory conditions) and for those in specific locations (such as on beaches, in the mountains, etc). These forecasts are explored in the next section (Section 6.3.1). In addition, the Met Office also provides specialist space weather forecasts, explored in Section 6.3.2.

The Met Office also provides a range of other specialist models. In particular, the Met Office's Numerical Atmospheric-dispersion Modelling Environment (NAME) is worth highlighting. NAME is used to model a wide range of atmospheric dispersion events such as nuclear or chemical accidents,

[22] Displaced mortality refers to the deaths of people who are already sick and close to the end of their life, whereas premature mortality refers to the deaths of otherwise healthy individuals.

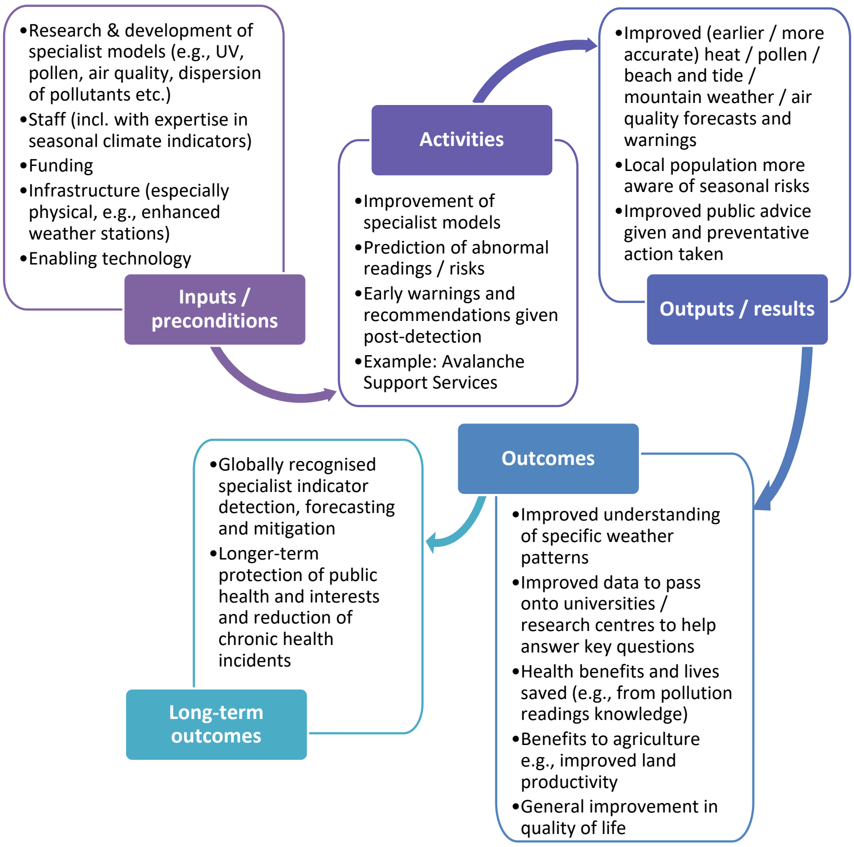
volcanic eruptions, smoke from fires, odours, and airborne animal diseases. However, due to the overlap with other benefit streams (e.g., volcanic ash with aviation, benefits to industry) these benefits were not evaluated separately to avoid double-counting.

6.3.1 Forecasts for people with specific needs or for specific locations

One of these specialist forecasting services is the pollen forecast, which provides information about the pollen prevalence over a 5-day period. The service enables those with pollen allergies to reduce their exposure to pollen and, as a result, experience fewer pollen-related health symptoms.

Another specialist forecast is the air quality forecast. This forecasting service provides information including emissions of pollutants and the transport and dispersion of pollutants by winds. This allows people with asthma and other health conditions affected by air quality to minimise the risk of an asthma attack or other respiratory symptoms by staying at home or adjusting outdoor activities.

Figure 7 Impact pathway: Specialist forecasts



Source London Economics

The Met Office also provides location specific forecasts including a beach forecast and tide times. These benefit the tourism sector and increases the safety of maritime activities. Moreover, the Met Office provides mountain weather forecasts, which can help to avoid deaths and injuries due to dramatic variations in mountain weather.

Figure 7 provides further details on the inputs, activities and benefits related to specialist forecasts.

Box 13 Evaluation of the value of specialist forecasts (baseline scenario)

Approach: As with the value of extreme temperature alerts, this study uses an avoided loss approach to estimate the value of lives saved from pollen forecasts. For this study, the health data and assumptions used are updated based on more recently available estimates. One caveat to this approach is that, due to a lack of evidence on the share of preventable deaths due to pollen forecasts, a conservative approach is adopted by applying the lower bound of the estimates found in the academic literature related to the share of preventable deaths due to extreme temperature alerts.

Results: The central results estimate a present benefit of £25 million (from 2024-2033) for the value of avoided deaths due pollen forecasts. This study estimates the value of lives saved due to the Met Office's pollen forecasts. Due to a lack of data, the value of lives saved from other specialist forecasts (e.g. air quality, beach forecasts etc.) could not be estimated, therefore the estimated value may underestimate the actual value of all Met Office specialist forecasts.

6.3.2 Space weather

The Met Office is also involved in forecasting and risk modelling space weather. Space weather describes the weather events that occur in natural space environments. Space weather events such as solar flares pose a significant risk to the operation of satellites and spacecraft. They can also cause large impacts on surface-based infrastructure such as electrical systems. In this way they can cause potentially substantial economic impacts[23] (e.g., damages to satellites and spacecraft, disruption in communication and navigation, outages of electricity systems).

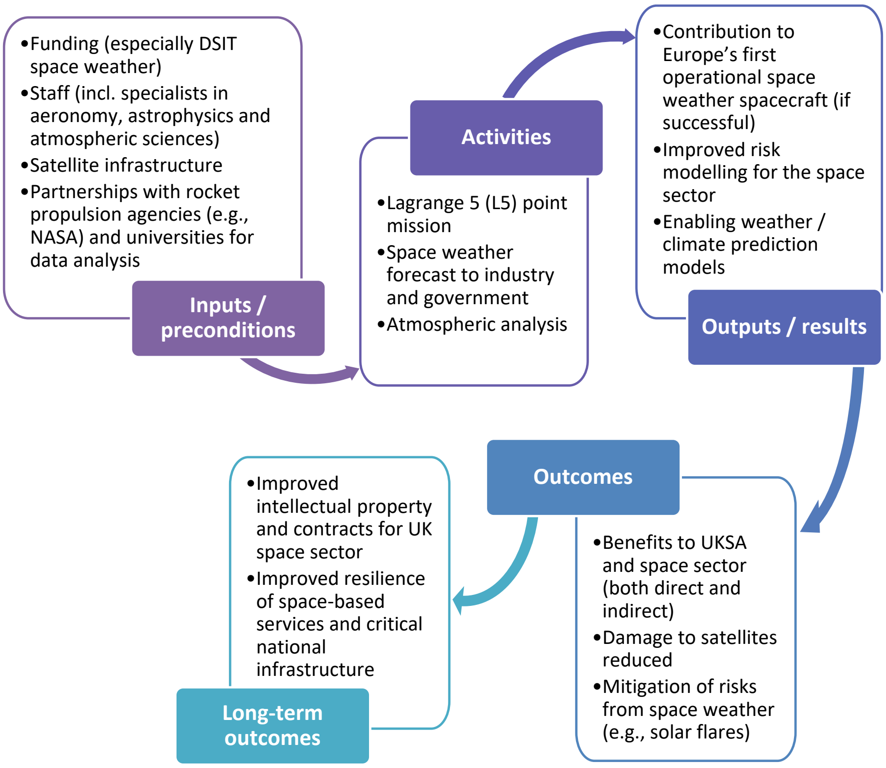
The Met Office's space-weather related research activities help improve the quality and accuracy of space weather forecasting and risk models. The forecasting information is used by governments and industries such as commercial satellite operators to better monitor and assess the space weather risk for the earth's space-based infrastructure. Space weather events could have potentially devastating impacts on the earth's critical terrestrial infrastructure including, among others, the electricity network, transport infrastructure and the aviation sector.

In addition, early space-weather warnings help space operators to mitigate space-weather related damage to the in-space infrastructure such as GPS systems. Moreover, Met Office space weather forecasts and risk assessments enable in-space operators to monitor and better mitigate the risk from space weather events such as solar flares.

The Met Office also contributes to the ESA Vigil Mission to launch Europe's first operational space weather spacecraft. This is intended to better monitor changing solar activities and provide earlier warning of damages from space weather (see ESA, n.d.).

[23] For example, Oughton et al. (2019) found that for a Carrington-sized 1-in-100-year event with no space weather forecasting capability could result in a GDP loss to the UK as high as £15.9bn. Based on their analysis this figure drops to £2.9bn with the then current forecasting capability.

Figure 8 Impact pathway: Space weather



Source London Economics

Box 14 Evaluation of space weather benefits (baseline scenario)

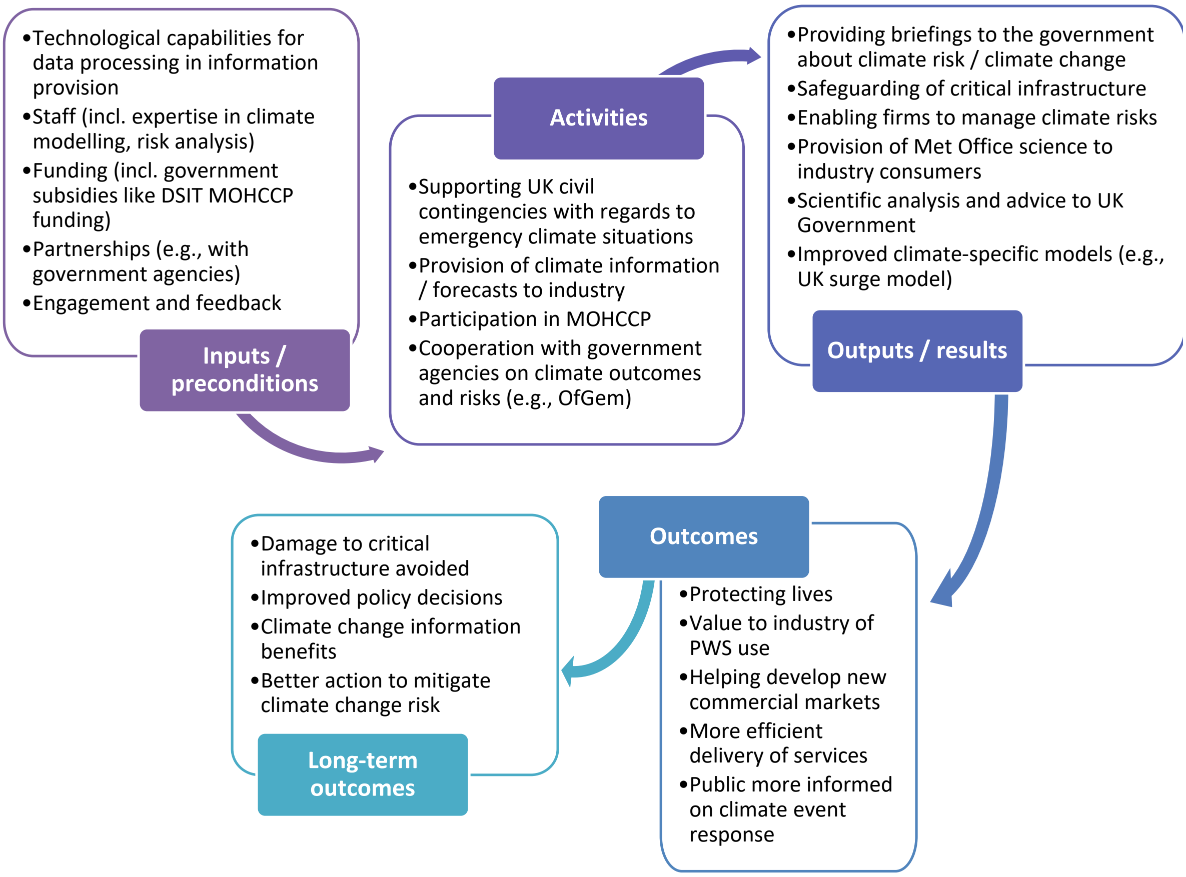
Approach: The present benefit estimate for the Met Office's activity in space weather forecasting is calculated by interacting the reduction in GDP loss from space weather forecasting from the literature with the share of space weather forecasting activity which may be attributed to the Met Office. The estimates in the literature relate to the impact of *severe space weather events* on the UK electricity sector only. Estimates of severe weather impacts on other UK sectors and the direct economic impact of *everyday* space weather could not be found , so they are not considered in this analysis. Therefore, the estimated benefit underestimates the full impact.

Results: The central present benefit was estimated to be £0.6bn, accounting for 1.1% of the total present benefit of the Met Office. This estimate is based on the current space weather forecasting capability, but the literature also provides a scenario with enhanced space weather forecasting capability. In the case of the enhanced capability the present benefit is estimated to be £0.7bn. Due to the uncertainty around attribution (assumed to range from 12% to 44% with a central assumption of 24%, see methodological annex) the sensitivity analysis suggests a relatively wide 95% confidence interval ranging from £0.4bn to £1.4bn.

7 Climate services

In addition to the fundamental climate research described in Section 9, the Met Office provides a number of services and products that help decision-makers to better understand the nature and impact of climate change and to better manage climate risks. This includes UK civil contingency responders, government departments, industry decision makers, as well as international organisations such as the Intergovernmental Panel on Climate Change (IPCC).

Figure 9 Impact pathway: Climate services



Source London Economics

A significant aspect of the Met Office's climate services is the UK Climate Projections (UKCP). The UKCP are a set of datasets and tools providing predictions on the likely change of the climate in the future. The UKCP projections are explored further in the case study provided in Box 16. The Hadley Centre, the Met Office's climate change research centre, produces the scientific output (predictive model, scientific knowledge, etc) which provides the foundation of the UK Climate Projections.

The Met Office also advises government departments and other public sector organisations directly (e.g., through policy briefings). For example, it advised the Department for Environment, Food and Rural Affairs (Defra) during the development of the Climate Change Risk Assessment (CCRA) and the National Adaptation Plan (NAP). These reports evaluate the combined risk of climate change to the UK and set out the actions that the government, among others, will take to adapt to the impacts of climate change in the UK (Defra, 2023). While the Met Office also offers climate advisory services to industry, the value of these services are captured within the industry benefits in Section 8 and are therefore excluded in this section to avoid double counting.

Figure 9 sets out the impact pathway for the Met Office's climate services, highlighting key inputs, outputs and outcomes. Similarly to the Met Office's weather services, the national capability plays a key enabling role for the Met Office climate services. These capabilities include observational datasets that capture the state and evolution of key climate variables (e.g., temperature, precipitation, as well as land observation data such air conditions, soil, and wind speed which is crucial for the UK climate projections). They also include the climate models that enable the prediction of the future climate.

In addition to the technical capabilities, the Met Office's climate science and research enabled by the Met Office's expert climate scientists, researchers, and modellers naturally underpins the provision of all climate services. The Met Office's scientific, innovation and technology activities, including the Met Office's climate and weather science, are explored in further detail in Section 9.

The short-, medium-, and long-term benefits of Met Office's climate services are explored below:

- In the short term, the Met Office's climate services improve stakeholders' (public, government, businesses, etc.) understanding of climate change. This better understanding helps stakeholders to better plan adaptation to and mitigation of climate risks such as flooding and extreme heat. An example of the adaptation actions is the safeguarding of critical infrastructure.
- In the medium term, the enhanced climate adaptation and mitigation plans improve and protect people's lives through mechanisms such as reduced green-house gas emissions (thereby reducing air-pollutants), or avoided damage to infrastructure or people's homes. This is especially the case in regions most severely impacted by climate change such as coastal regions. Moreover, commercial markets are likely to grow or emerge to deliver the enhanced adaptation/mitigation measures. An example of this is the demand for renewable energy sources to reduce reliance on fossil fuels.
- In the long term, the Met Office climate services generate climate change information benefits that reach far into the future (the UKCP18 project climate changes until the year 2100). For example, by enabling policymakers to design adaptation policies that improve the lives of future generations and enhance the resilience of the UK to future climate risk.

Estimating the benefits of improved climate adaptation is inherently difficult and uncertain. However, studies providing estimates of the socioeconomic value of receiving climate information earlier, and thereby being able to better plan and adapt, do exist.

Box 15 Evaluation of climate adaptation benefits (baseline scenario)

Approach: A separate evaluation study of the benefits of the Met Office Hadley Centre Climate Programme (MOHCCP) was undertaken by London Economics for the Department for Energy and Net Zero (2024). The MOHCCP evaluation, based on a review of existing evidence and stakeholder consultations, identifies three benefit categories for the value of climate information: i) updating emission targets; ii) supporting mitigation measures; and iii) supporting adaptation measures.

Based on this evidence the MOHCCP evaluation estimates likely minimum benefits attributable to the Hadley Centre Climate Programme for the period 2018-21. Given the work undertaken for the MOHCCP evaluation, the current study does not directly estimate climate benefits to avoid duplication of work. Instead, central climate estimates presented here are based on the results of the MOHCCP evaluation. However, the MOHCCP study only focuses on benefits associated with three years of climate research at the Hadley Centre (2018-21). In contrast, this study focuses on benefits associated with Met Office Climate Research over the next ten years. The estimated benefits from the MOHCCP evaluation are therefore scaled to a ten-year period.

Results: Preliminary results of the Hadley Centre evaluation (see A2.1.2) suggest likely minimum benefits attributable to the MOHCCP 2018-21 in the region of around £1.9bn. This is based on six identified studies capturing benefits in the three categories mentioned above. The maximum benefit attributable to MOHCCP 2018-21, across the six identified studies, was around £28.3bn. This is based on results by Watkiss et al. (2022). Two studies, Hope (2013), and Rising et al. (2022), identify more moderate benefits in the region of around £12bn. Values obtained from these studies are used as the central estimate in the current analysis.

Accounting for differences in time horizons would imply benefits of between £6.4bn and £94.4bn associated with Hadley Centre climate research over the next decade. The scaled up central estimate would imply benefits in the region of £12.0bn. These figures are in line with the Met Office's own internal modelling[1], which implies a central benefit estimate in the region of around £13.2bn. This is based on an updated climate methodology developed by Ross (2019c) and reviewed by Cambridge Econometrics (2019). The central estimate is calculated as the average of the model's uncertainty range of between £2.3bn to £24.0bn.

However, the MOHCCP evaluation estimates only capture the benefits of climate research within the remit of the MOHCCP and are therefore an underestimate of the total Met Office climate activity. Moreover, the likely minimum benefit implied by the MOHCCP estimates is more than twice as large as the lower bound implied by the methodology suggested by Ross (2019c), while the upper bound suggests potential benefits might be substantially larger than the implied range. This suggests that whilst they are sensible, estimates following Ross (2019c)are likely on the conservative side.

In line with decisions to err on the side of caution throughout this analysis , the lower estimate of £12bn is used as the central value for climate benefits. However, it is plausible that benefits could be substantially larger than implied by these central estimates. Therefore, the likely minimum benefits of £6.4bn and the largest estimate among six studies of £94.4bn estimate from Watkiss et. al. (2022)are used as the lower and upper bounds in the sensitivity analysis around this central estimate. However, achieving benefits at the upper bound is much less likely. This is accounted for in the sensitivity analysis. The resulting 90% confidence interval suggests a lower range of plausible benefits of between £8.3bn and £53.7bn.

(1) The figures reported are based on London Economics' analysis of the Met Office's internal model. They represent the model's implied benefits for research undertaken over the study period (2024-2033), discounted using the HM Treasury discount rate of 3.5%.

Box 16 Case Study: From projections to resilience - The value, and pathways to impact, of the UK Climate Projections

What are the UKCP?

The UK Climate Projections (UKCP) are a set of visualisations, datasets, guidance documents and case studies, produced by the Met Office Hadley Centre. The UKCP include projections (covering land and marine environments) under different emission scenarios and observations of current and past climate conditions.[i] The most recent version of these tools and datasets was developed in 2018 (UKCP18); while some other products were released later in the year in support of CCRA4. The **UKCP18 consists of projections**, covering both land and marine environments, and **observations** of current and past climate conditions[ii]:

- **Global, regional, and local land projections** provide information about the variation of key land-related climate variables (e.g., temperature, precipitation) in different future emission scenarios and different regional resolutions (60km, 12km and 2.2km) in the UK.
- **Probabilistic projections** show how climate variables change in different future greenhouse-gas-emission scenarios, with a spatial resolution of 25 km, based on an evaluation of model uncertainties.[iii] Moreover, the UKCP include Probabilistic Projections of Climate Extremes, which contain information of extreme weather conditions (temperatures and precipitation) in the 21st century in the UK.[iv]
- **Derived projections** contain a set of climate futures, which are derived from the global projections, simulating a scenario with lower emissions and global warming levels.[v]
- **Weather and climate observations** include a comprehensive set of past climate and weather observations (e.g., temperature, wind speed) up to 150 years back in time. These are referred to as the HadUK-Grid datasets and are available at 12km, 25km and 60km resolution.[vi]
- Lastly, the UKCP18 delivers **marine projections** about average sea level rise on UK coastlines, in addition to extreme water level projections, covering storm surges and tides.[vii]

Most of the projections are produced by the Met Office Hadley Centre in collaboration with the Environment Agency (EA) using models developed in-house. Some of the scenarios of the global projections are based on the CMIP models of the World Climate Research Programme.[viii] Apart from the local projections, all climate projections cover the years up to 2100. Moreover, the key information from the UKCP18 is summarised by the Met Office Hadley Centre, EA and government departments, and is freely available online as summary and guidance documents.[ix] These documents contain guidance on how to interpret the UKCP, how to use different sets of land projections or how to access the UKCP.[x]

How are the UKCP accessed, who uses them?

The UKCP18 are **accessed by a wide variety of users**. First and foremost, the information included in the UKCP18 is publicly available through the UKCP user interface[xi]. Here the projections are disseminated in a variety of ways including maps, graphs, and datasets (e.g., panel data by regional units), as well as guidance and factsheets, science reports, technical notes, and slide packs. Moreover, other UKCP data is disseminated through the Centre for Environmental Data Analysis (CEDA).[xii] UKCP data can also be accessed through the Met Office Climate Data Portal.

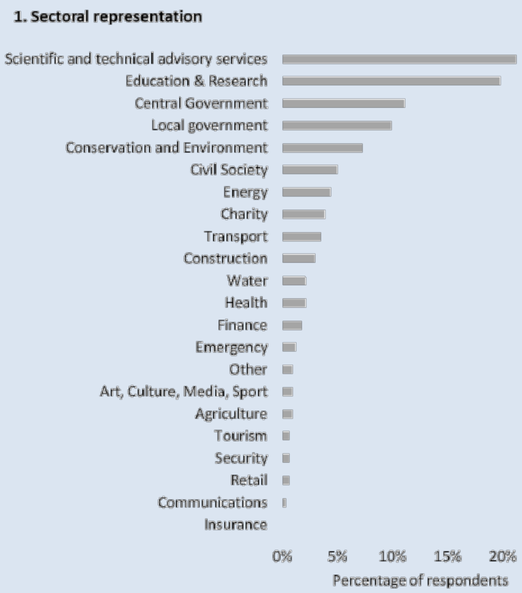
Major users include government departments, independent climate centres and academia, as well as businesses. Within government, Defra, DESNZ and the Environmental Agency are major users of the UKCP18.[xiii] Other users include climate researchers from research centres and universities, the Climate Change Committee (CCC), the Ministry of Defence, users from industries (e.g., aviation, financial sector), media outlets and members of the public.

Due to the variety of channels through which UKCP are used (further discussed in the next section), it is difficult to provide a full picture of the user breakdown. Information on the data being accessed, which can provide insights on users accessing UKCP, is only part of the picture. More importantly **UKCP feature extensively in guidance related to UK adaptation process as well as wider climate services and academic research.** For example, the UKCP feature in the UK government's Climate Change Risk Assessment's as well as the National Adaptation Programme. Nevertheless, figures 1 and 2 provide an indication of the main sectors in which users operate.

Figure 1 shows the sectoral breakdown of the users of the UKCP climate information based on a climate information user survey carried out in February 2022/23. It shows that most users come from scientific and technical advisory services, education and research and government. This shows that UKCP is important for the UK adaptation programs and climate risk assessments, wider climate services and academic research.

Figure 2 shows the sectoral breakdown of users accessing the UKCP User Interface in Q4 of 2022/23, providing some insight on the uses of the UKCP18. However, this only covers users accessing the UKCP via its user interface. It therefore excludes a substantial number of users accessing the UKCP through other channels discussed below.

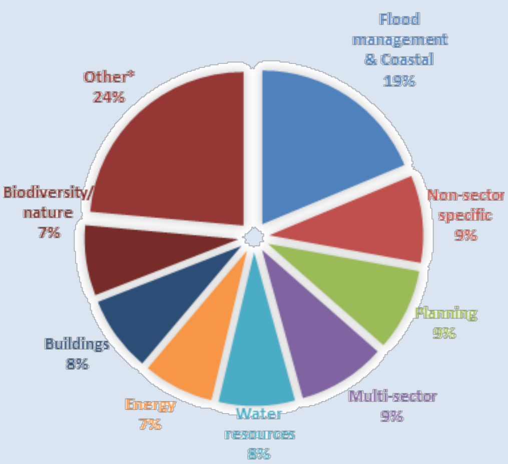
Figure 1 UKCP User Breakdown (overall) (February 2023)



Note: This breakdown is based on 345 survey users. Despite potential sampling bias due to non-random sampling design, the graph provides some indication of the distribution of users.

Source: Met Office (2023). The state of climate information use in the UK: Summary of survey results (February 2023)

Figure 2 UKCP User Interface – User Breakdowns (2022-2023 Q4)



Note: *includes all sectors under 5% (agriculture & horticulture, transport, services, financial services, health & healthcare, defence & security, emergency planning & services, forestry, heritage, waste management, manufacturing & industry, leisure & tourism & lifestyle, fisheries, telecommunications, retail. Note that about 50% of users do not specify a sector.

Source: Met Office (2023). Met Office Hadley Centre Climate Programme: Quarterly Report contributions, 2023-2024 Q1

How are UKCP used and communicated?

As UKCP are freely available online, users can include UKCP information in their own products and services. Thus, the UKCP information is further disseminated and has an impact through the products and services which are enabled through UKCP. This constitutes one of the major channels through which UKCP are used. An example of this is climate models created by academics which are then used to predict climate events.

However, as the UKCP are quite technical[xiv], it is important to translate the information into a format which is accessible and usable to a wide range of users from different backgrounds, and tailored to the needs of specific users (e.g. Defra). Therefore**, in addition to providing the UKCP via its website, the Met Office disseminates the UKCP through a variety of channels**. This includes briefings to policymakers, consultancy activities, inclusion in other products and services, and many more.

The Met Office undertakes many additional activities to ensure the information is useful and ultimately delivers socioeconomic benefits to the UK, for example:

- The Met Office, through its KI team and UKCP climate services (funded by Defra), **translates and synthesises the information** from the UKCP **into a format suitable for a broad audience**. The team holds briefings with government departments (e.g., DESNZ, Defra), delivers teaching sessions, and produces written reports, summaries and policy briefs.[xv] The main aim of these activities is to support policymakers use and understanding of the UKCP to inform and develop mitigation and adaptation strategies to reduce the future costs of climate change.
- The Met Office also **supports government departments such as Defra in the utilisation of UKCP**. For example, the Met Office seconds climate scientists or communication experts in other departments to provide scientific support and insights from within these organisations. In addition, the Met Office also provides briefings, advice and wider external support to government departments. For example, it supports the design of climate adaptation measures and helps to ensure that climate policy, such as the Climate Change Risk Assessment (CCRA) and National Adaptation Programme (NAP), are underpinned by the latest scientific evidence. In addition to government departments, it provides advice to organisations such as the Climate Change Committee (CCC) as well as private companies (e.g., in the energy and water sectors).
- The Met Office also **develops more specific climate services** that are **based on the UKCP** and tailored to specific user needs. For example, the applied science team at the Met Office develops delivers climate and weather information (based on UKCP) to Britain's National Rail Network to inform decision-making and planning for present and future operations.[xvi] The team also develops the climate data portal, which make UKCP information more accessible to non-technical users.

How does the UKCP help mitigate climate impacts?

The UKCP deliver socioeconomic impacts through a variety of ways. As a scientific output, the UKCP directly contribute to **improved climate science and a better understanding of climate change**. Moreover, the UKCP also contribute to further climate science indirectly as an input to further research. For example, by providing a rich dataset including detailed historical as well as regional observational data the UKCP can help improve the predictive power of other climate models, which use UKCP data as an input in their own predictions. This is illustrated when considering Google Scholar results, which, as of November 2023, show around 1,150 results mentioning UKCP18. In addition to climate science itself, the UKCP can also support climate-related innovation more generally. For example, enhanced understanding of the specific climate variables (such as specific local geographic areas) that are likely to be significantly impacted by climate change, enables development of innovations that can help minimise changing climate effects in these cases.

Access to more accurate, UK-specific, climate projections **enables policymakers, planners and practitioners to develop better climate adaptation plans**. For example, this contributes to better avoidance and mitigation of damages to critical infrastructure due to climate change. Similarly, it allows policymakers (and industry) to develop and implement mitigating measures to reduce climate impacts on key climate-sensitive sectors of the economy such as agriculture and tourism. Improved (or indeed enabled) mitigation measures in turn can make a significant impact on the livelihoods of whole communities in the UK. For example, coastal communities can be better protected from sea-level rises.[xvii] The UKCP also **helps policymakers, planners and regulators set better environmental targets** and provides individuals and businesses with better information about the impact of Greenhouse gas (GHG) emission on climate change. This allows them to adjust their behaviour and reduce their environmental impact, thereby reducing UK and global GHG emissions. For example, information relating to the emissions associated with different means of transportation allows users to make an informed choice about the way they travel.

The transport sector is one concrete example where UKCP insights feed directly into policymaking and through this deliver real-life benefits to the UK. The Met Office provides climate projections, as well as climate insights and advice, to the Department for Transport (DfT) and its public bodies to support the design and implementation of specific mitigation measures for the UK transport infrastructure. For example, current Met Office secondees work directly with the climate adaptation team at Network Rail (an arms-length body of the DfT) to define climate and weather thresholds under different emission scenarios. In the context of railways, an example of these thresholds are extremely high temperatures that imperil the railway infrastructure. Met Office impact modelling helps understand if, when and how often the thresholds are likely to be exceeded, thereby allowing definition of intervention plans to safeguard assets and avoid damages from changing climate.[xviii] Another example is the incidence of heavy rain, which poses a risk of culverts spilling over and system surcharges in the UK. Through better knowledge of the changing probability of heavy rain for particular emission levels, culvert size and capacity can be uprated, and damage prevented.[xix]

The Environment Agency, one of the biggest users of UKCP, refers to UKCP in its own statutory guidance for flood planners. The EA uses data from the Met Office, alongside data from the Centre for Ecology and Hydrology which uses UKCP data, as an input to their own river flooding models. For example, the EA use UKCP data to estimate uplifts in flooding risks such as the likely increased incidence of river flooding and sea level rises in future. Based on this, they develop metrics, guidance and **flood defence strategies**. Local planners need to heed this guidance when reviewing their planning applications, thereby ensuring up-to-date climate knowledge is utilised to ensure better mitigation of damages from flooding.[xx]

There is a wide range of further examples of UKCP being used in a range of policy-areas to bring about socioeconomic impact. One such example of this are regulations in water resource management. Water companies have an obligation to OFWAT to, every five years, demonstrate their contributions to UK climate resilience and safeguarding water resources against climate events.[xxi] The Office for Nuclear Regulation also makes use of UKCP to assess the risk of sea-level rises and other climate events. This helps them to ensure the safety of energy supply and to avoid nuclear damages and to better plan or construct new sites. The UKCP also inform policies to mitigate the impact of climate change on our health, as highlighted by the UK Health Security

Agency (UKHSA) extensive use of the UKCP in their own reports on the effects of climate change on health.[xxii] Moreover, the national infrastructure commission uses the UKCP for risk assessments in national infrastructure planning. They highlighted the need to make climate projection data more accessible and to integrate it more into infrastructure risk assessment.

What happens in the absence of UKCP?

The previous section has highlighted a range of areas where the UKCP are delivering substantial socioeconomic benefits. However, to establish the additional value the UKCP bring, one has to consider whether these benefits would materialise in the absence of UKCP. While this is a difficult question to answer, there is some evidence to suggest the UKCP are critical to the realisation of many of the listed benefits. Firstly, in a survey about user engagement with the UKCP, the Met Office collected data on the sources of climate information that **'non-users' of UKCP18 use.** Most of these alternative climate information services/products use UKCP data as an input (e.g. CORDEX).[xxiii]

However, some such as the global projections from the CMIP6 can be compared with global land projections of the UKCP.[xxiv] In the absence of the UKCP, national adaptation strategies such as the UK climate adaptation programmes and risk assessments could therefore use the projections of the CMIP6. However, CMIP6 does not provide the same granularity. Design of accurate and effective adaptation measures and risk levels at regional and local levels in the UK require regional and local climate projections, which are not provided by CMIP6. Stakeholder consultations and other studies have shown that there are no alternative climate products/services to the UKCP with a similarly high UK-specific spatial resolution. Hence, while other projections could be used at a national level, the UKCP are absolutely necessary to produce detailed regional and localised climate risk assessments and adaptation programmes for the UK context.[xxv]

Summary

In summary, the UKCP provide significant socioeconomic value to the UK (and beyond) by making climate adaptation programmes more effective and accurate. This contributes to increasing our overall climate resilience and to reducing climate-related damage to critical infrastructure, the economy and society. The users of the UKCP are diverse, covering climate researchers, policy makers and businesses. UKCP information is disseminated through a variety of ways including synthesised reports and briefings, customised datasets and climate services, and by working directly with government departments and other users (e.g., via briefings, consultancy activities or through secondees). UKCP users themselves also use the UKCP in their own third-party products and services, further increasing the reach and impact of the UKCP.

Case Study References:

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[xi] Accessible here: https://ukclimateprojections-ui.metoffice.gov.uk/products
[xii] CEDA Archive (2018) About [Online] Available here (Accessed: 01/09/2023)
[xiii] DEFRA (2023) *The Third National Adaptation Programme (NAP3) and the Fourth Strategy for Climate Adaptation Reporting* [Online] Available here (Accessed: 01/09/2023)
[xiv] For example, the observational datasets are very large and need to be manipulated and cleaned to extract the information needed.
[xv] For example, in the form of headline findings: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp-headline-findings-v2.pdf
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[xviii] London Economics' consultation with a Met Office secondee at the Department for Transport.
[xix] Network Rail (2021) *Third Adaptation Report*.[Online]. Available here. (Accessed: 11/02/2023)
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[xxii] UK Health Security Agency (2023) Health Effects of Climate Change [Online] Available here (Accessed: 31/01/2024)
[xxiii] Met Office Hadley Centre (2023) Hadley Centre Technical Note 109: Comparison between climate change projections from the UKCP land scenarios and CMIP6 models [Online] Available here (Accessed: 31/01/2024)
[xxiv] Ibid.
[xxv] Arup (2023) TTWO0214 – Review of Tools, Mechanisms and Guidance for Climate Risk Assessments [Online] Available here (Accessed: 31/01/2014)

8 Industry benefits

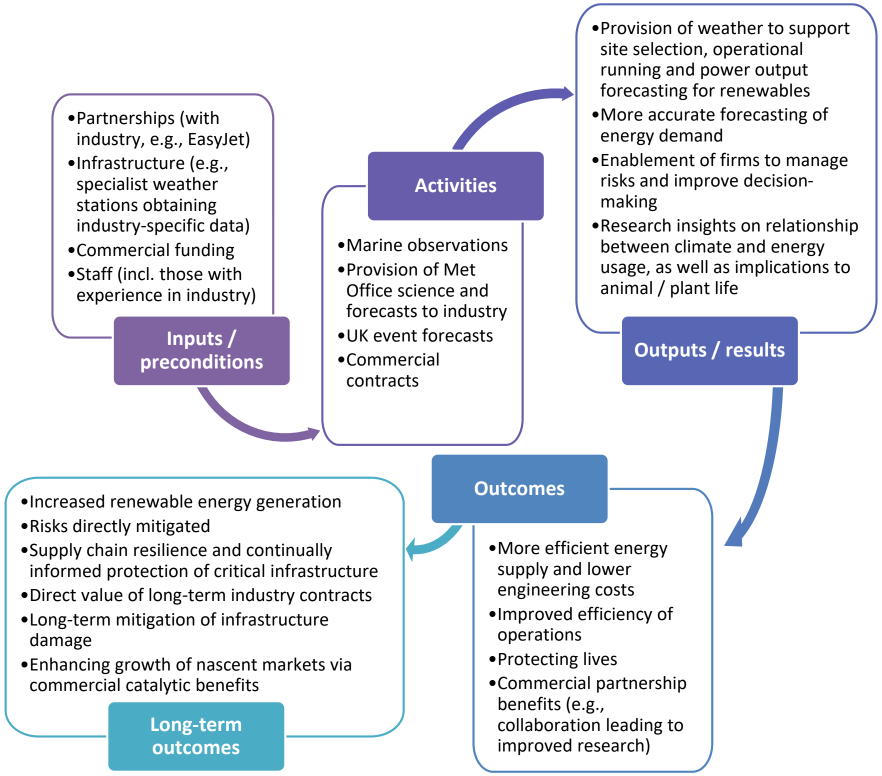
The Met Office delivers value to industry through three primary avenues: Regulatory-mandated services to the aviation sector, advisory services for commercial enterprises, and the provision of public weather information and accessibility of publicly available data.

As a provider of regulatory-mandated services to the aviation industry, the Met Office is one of only two World Area Forecast Centre (WAFC) in the world. In this capacity, the Met Office offers vital upper-level wind and temperature forecasts, as well as forecasts for turbulence and icing, for flights worldwide. This contributes to flight safety and the optimisation of fuel consumption. Additionally, the Met Office runs the London Volcanic Ash Advisory Centre (VAAC). This is an International Civil Aviation Organization (ICAO) sanctioned facility, that assumes the responsibility of issuing advisories pertaining to volcanic eruptions originating in Iceland and the north-eastern sector of the North Atlantic.

The Met Office also provides advisory services to industry on weather and climate-related challenges. These services empower businesses to navigate the intricacies of daily weather patterns, mitigate the impact of extreme events, and strategically prepare for future climate conditions. Examples include providing forecasts for sporting events and leisure services, informing critical decisions regarding infrastructure investments and construction, and long-term strategic planning.

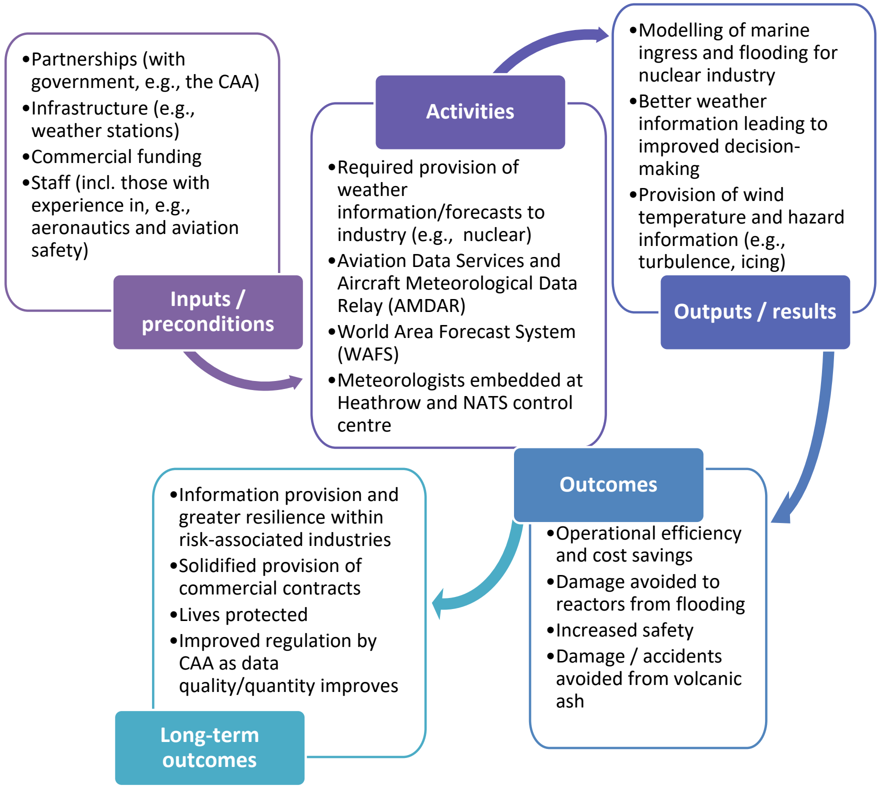
In addition to these tailored services, businesses benefit greatly from accessing publicly available weather and climate information from the Met Office. Businesses are able to use this information to inform their decision-making. This allows businesses to proactively plan for upcoming weather events and enables the creation of effective contingency plans. A small number of examples where provision of public weather information impacts decisions made by businesses are provided in Box 9 in Section 6.1. Moreover, the private weather sector can also use publicly available data by the Met Office in their own products and services, thereby stimulating the private weather sector.

Figure 10 Impact pathway: Advisory services to industry



Source: London Economics

Figure 11 Impact pathway: Regulatory-mandated services to industry



Source: London Economics

8.1 Impact of provision of weather information on industry

Many sectors are directly or indirectly impacted by weather and/or climate conditions, and businesses benefit greatly from accessing publicly available information from the Met Office to inform their decision-making. This allows them to proactively plan for upcoming weather events and create effective contingency plans. For example, organisers of outdoor events may seek to reschedule or cancel events in case of severe weather. Alternatively, they may provide weather protection such as marquees or, if possible, move the event indoors. A few other select examples where the provision of weather information impacts decisions made by businesses and other organisations are provided in Box 17.

Box 17 Examples of micro-decisions made by industry based on weather information

Agriculture:

- Decisions about when to plant or harvest crops.
- Adjusting irrigation based on rainfall predictions.
- Protecting livestock from extreme temperatures.

Construction and infrastructure:

- Deciding whether to continue or halt construction based on potential rain, storms, or winds.
- Planning for supply chain disruptions due to predicted weather events.
- To help with the resolution of contract disputes & compensations.
- Designing infrastructure to withstand local weather conditions, such as bridges that can tolerate high winds or roads that can handle heavy rainfall.

Energy:

- Grid operators use the weather forecast to model energy demand and supply.
- Renewable energy sectors, such as wind and solar farms, adjust maintenance schedules based on weather predictions.
- Safety-critical planning decisions for new energy reactors.

Events and entertainment, **restaurants, and media:**

- Deciding whether to seat customers indoors or outdoors, protecting inventory by putting up umbrellas or handing out blankets and switching on space heaters.
- Organisers might cancel or reschedule events, especially large outdoor events, due to weather forecasts.

Retail, commerce, and media:

- Stocking seasonally appropriate goods, such as umbrellas, snow shovels, or air conditioners.
- Seasonal sales and promotions based on upcoming weather trends.
- Deciding on broadcast and digital services/programmes to attract viewers / gain sponsorship or other revenues, and the running of marketing or sales campaigns.

Travel and transportation:

- Deciding whether it is safe to drive, especially in conditions such as fog, heavy rain, or snow, or adjusting routes due to weather-related road closures, and to make a decision about long distance travel including by rail and flights.
- Sailors and fishers check weather forecasts, especially for storm warnings or tidal information.
- Airlines and airports decide how to manage the movements of aircraft on the airfield or if flights can operate based on weather information. Similarly, train operators use weather information to inform decisions on how to manage impacts of weather on the rail network.

Box 18 describes the approach taken to value efficiency gains for UK businesses resulting from actions they take in response to weather information and services provided by the Met Office. Benefits for some sectors, such as aviation and winter transport, are estimated separately and are therefore excluded in this benefit stream to avoid double counting.

Box 18 Evaluation of the impact of provision of weather information on industry (baseline scenario)

Approach: The total benefits associated with the provision of weather information to industry was calculated following the approach taken by Ross (2019a) in their estimate of the socio-economic benefit of improved forecast services to the UK economy.

The estimation looks at GDP that could be impacted by weather, independently for each sector, and combines this with a number of assumptions regarding the effectiveness of response by businesses to forecast information, the accuracy of forecasts and the engagement of firms with forecasts (please see the methodological annex for more detailed information).

This method improves upon the method used in the 2015 General Review by considering the behavioural response of users (i.e., what proportion of businesses are aware of the information, what businesses do with the information provided, and the effectiveness of actions taken).

However, some of the assumptions are now somewhat outdated. For example, key assumptions on the weather sensitivity of different sectors are based on a relatively old study by Lazo et al (2011). Similarly, behavioural assumptions rely on a 2018 survey of UK SMEs. This study is now also several years out of date. Further, it only considered a narrow scope of SMEs. Therefore, future primary research to update these assumptions (e.g., similarly to that undertaken for the value to the public) would be valuable.

Results: The central results indicate a present benefit of £10.9bn over the ten-year study period (2024-2033). This accounts for just under one-fifth (19.4%) of the total present benefits and is the second largest benefit stream. This figure is likely to be a conservative estimate:

- Using the approach[24] taken for the General Review yields a central estimate of £14.0bn, with a minimum estimate of £5.6bn and a maximum of £22.5bn.
- The 90% confidence interval of the sensitivity analysis suggests the total benefit could be as large as £17.3bn, whilst a lower bound estimate suggests this benefit stream would amount to £6.3bn.

[24] Note that the estimate for this report used a different methodology which focuses on each sector independently, whereas for the General Review the estimate was based on 17% of all GDP being weather sensitive.

- The approach excludes a number of industry sectors to avoid a potential double counting with other benefit streams[25]. Importantly, these include the finance, insurance and real estate sectors (to avoid overlap with extreme weather warnings), transportation and storage (to avoid overlap with winter transport and aviation benefits), and public administration and defence (as defence is out of scope).

8.2 Benefits to industry resulting from the Met Office's consulting and advisory activities

The Met Office provides direct advice through consulting activities to a number of industry sectors, including agriculture, construction, energy, event management and water sectors. In addition, the Met Office also has commercial contracts with a number of firms for provision of specialist weather information products. A selection of concrete examples include:

- **Aviation:** Regulated services provided to the aviation industry, such as provision of flight critical weather information, enhancing flight safety and operational efficiency for airlines as well as additional services such as onsite forecasters (e.g., at Heathrow Airport).
- **Demand/supply forecasting for energy sector (ESO):** Met Office advice helps the energy sector to accurately anticipate demand, and supply from variable renewables, and therefore the contribution needed from different energy sources. This ensures sufficient energy can be delivered when it is needed and that the cost of energy is kept low. Met Office forecasts also help the energy sector make informed decisions about supply decisions of renewables.
- **Planning for future – the impact of climate change and net zero:** Longer-term, the Met Office works with the National Grid and energy providers to help understand and optimise the energy mix required into the climate periods. This includes work with energy providers to help them make the right investment decisions, leading to potentially substantial cost savings.
- **Resilience benefits:** Met Office advice can help companies understand future impacts of heat, droughts, wildfires and their current resilience and what mitigation measures they may need to put in place.
- **Advice to help manage the strategic road network:** The Met Office advises National Highways, covering England, and Transport for Scotland to help them manage the strategic road network, particularly in the wintertime.
- **Maritime:** The Met Office has an ongoing relationship with the Maritime & Coastguard Agency who it helps to provide shipping forecasts and gale warnings, among others. It also increasingly works with the Royal National Lifeboat Institution (RNLI) to promote messages to keep the public safe (e.g., promoting beach safety in windy conditions).
- **Rail:** More recently, the Met Office has started to advise the rail sector. For example, when there is severe heat to evaluate the heat impact on the rail network and to put mitigating measures (such as speed restrictions) in place.
- **Space weather:** The Met Office monitors the level of solar and auroral activity and can advise on how this may impact critical national infrastructure. This can help keep critical infrastructure safe.
- **Spaceports**: Met Office weather advice supported the horizontal space launch of Virgin Galactic earlier in the year. Going forward the Met Office will also be supporting anticipated

[25] Full details of excluded sectors are provided in A2.1.4.

launches from the Shetland islands supporting anticipated flights (with a potential of around 10-15 flights per year from Shetland).

Some of these benefits are already captured in the evaluation of other sectors (e.g., aviation and winter transport). However, other sectors are currently not covered and present gaps in the evaluation. In some cases, these are notably large. For example, the benefits of cost savings to infrastructure decisions in the energy sector, or the future support of space launches.

Box 19 The value of consultancy and advisory activities – government dividend (baseline scenario)

The Met Office's consultancy and advisory activities deliver substantial benefits to industry, government and other organisations. However, these benefits are both difficult to evaluate and, at least in part, are already captured via the valuations of other evaluated benefit streams. Therefore, to avoid double counting, these benefits are not evaluated separately. The present value of the revenue accrued by the Met Office is estimated to be around £3.4bn across the 2024-2033 period. As a direct benefit to the Met Office, this figure is included in the overall benefits estimate. However, it is excluded from the return on public investment, as commercial contract revenues are a transfer payment from UK businesses to the Met Office so they have a net-zero benefit to the UK taxpayer. Nevertheless, as the Met Office is a trading fund, the Met Office generates a dividend which is paid to the government. This stream is counted in both the revenue and overall benefit stream. This figure is assumed to be constant at £8.5 million across the entirety of the period, resulting in a total present benefit of £73 million.

8.3 Sector specific impacts

8.3.1 Aviation

The Met Office has multiple aviation services, aiming to enhance flight safety and operational efficiency for airlines, other air transport companies, and the UK military (see Section 10.2). A core service delivered is the required provision of weather information and forecasts. This is facilitated through government partnerships such as the Civil Aviation Authority (CAA). Meteorologists working alongside the Met Office are stationed at key airport control centres such as Heathrow to monitor and provide expert regulatory services.

Other activities include Aviation Data Services, the Aircraft Meteorological Data Relay (AMDAR), the World Area Forecast System (WAFS) and the Volcanic Ash Advisory Centre (VAAC). These services use a combination of data from worldwide weather stations, onboard aircraft sensors, and specific airport-based sources to generate insights for aircraft, enabling them to plan optimal flight paths while accounting for weather conditions. Furthermore, these services benefit from commercial partnerships and funding contributions from airlines such as EasyJet as well as collaborative efforts with aviation safety experts in the industry.

Access to better information and provision of indicators, such as wind temperatures and hazard information, improves decision-making in the aviation industry. This brings about important safety benefits as well as efficiency gains. For example, there is a reduction in accidents, infrastructure damage and delays caused by adverse winds. Or, significant cost savings and environmental improvements can be made when de-icing fluid is not deployed at an airfield.

Beyond operational efficiency and cost savings, there are also significant benefits in terms of lives saved. In the long term, these services lead to enhanced regulations through improved data quality and quantity. This, in turn, bolsters resilience in industries that manage significant risk, as they now have a greater wealth of data available to them.

Box 20 Evaluation of the value to aviation (baseline scenario)

Approach: The benefit stream associated with the value that the Met Office brings to the aviation industry is split into two components. First, the international benefits of the value of the Met Office's contribution to the World Area Forecast Centres (WAFC). Second, the national cost savings associated with weather impacts at UK airports, including aircraft costs (fuel, crew, maintenance), passenger costs (lost time), costs of cancellation and costs of diversion.

This approach follows the methodology used in the 2015 General Review. However, the current analysis uses updated data on the number of flights each year to estimate the benefits for the period in question.

Results: The central results estimate a present benefit of £12.5bn from 2024-2033. This accounts for around one-quarter (22.3%) of the total present benefits and is the largest benefit stream. The 90% confidence interval of the sensitivity analysis indicates that the benefit could be up to £16.4bn, whilst the total benefit is unlikely to be lower than £9.7bn.

For comparison, the previous 2015 General Review estimated aviation benefits at £9.2bn. This is equivalent to £11.6bn in 2024 prices. Therefore, the current estimate is higher by almost £1bn. The difference is driven by the forecasted increase in the number of flights each year across the period in question.

The value associated with cost saving at UK airports (70.5%) accounts for the largest share of aviation benefits. The international value of the WAFC accounts for around a third (29.5%) of the total benefit for aviation. However, as the value of WAFC is international some of this benefit will accrue outside the UK.

8.3.2 Winter transport

The Met Office provides significant value to the road transport industry and the driving public. This is through both advisory services to transportation providers and the provision of weather information itself. Since a substantial share of weather-related costs in the transport sector occur in winter (see The Winter Resilience Review Panel, 2010), the Met Office's transport-related services and products have historically been tailored to winter transport. However, the Met Office is increasingly providing non-winter transport advice, such as to the rail sector or relating to heat-impacts on the transportation sector.

One example of a Met Office product for the transportation sector is the Met Office's road surface forecasting *OpenSite*™. This provides transportation firms with data on surface and air temperature, and the overall state of the roads, in high regional and temporal granularity (hourly)(Met Office, n.d. a). Met Office weather forecasts also provide accurate information on precipitation, snowfall, and road conditions. This can help people make better-informed decisions about their behaviour in winter traffic.

Met Office services and products related to road transport generate significant benefits. In the short term, Met Office advisory services help transportation providers in their decision-making thus helping minimise delays and avoid costs. Met Office advice also helps safeguard critical infrastructure from extreme winter weather conditions.

Moreover, by keeping the public and industry road users informed about critical winter weather through Met Office forecasts enables drivers to adapt their behaviour (e.g., driving more slowly or not at all, taking alternative transport means, or indeed not using the car in expectation of bad driving conditions). This helps avoid damage from road accidents which may not have happened had accurate and easy to access weather forecasts been available.

In the medium-term, transportation providers can increase the overall efficiency of their operations and reduce costs, which generates further economic benefits. In the long term, lives are saved, and the overall resilience of the infrastructure and mitigation strategies are improved.

Box 21 Evaluation of winter transport benefits (baseline scenario)

Approach: The benefits associated with winter land transport consider the UK public's response to winter weather forecasts and the total 'hard' costs of winter weather. 'Hard' costs include the impact of weather on economic output, as well as the costs associated with road and pedestrian accidents caused by inclement winter weather. This approach follows the methodology in the previous 2015 General Review.

Results: The central present benefit estimate for this stream is £1.5bn across the ten-year study period (2024-2033). This accounts for 2.7% of the total monetised present benefits of the Met Office. The 90% confidence interval from the sensitivity analysis suggests the total benefits could plausibly be as high as £3.0bn, and that they're unlikely to be any lower than £0.6bn.

Assumptions on 'hard' costs used in the evaluation of winter transport benefits are reliant on the 2010 Winter Transport Resilience Review (DfT, 2010). These are therefore now somewhat out of date. While newer iterations of the Winter Transport Review have been published, these do not contain valuations of winter transport benefits.

Informal assessment of the value of lives saved from avoided weather-related winter road deaths in England suggests that the total benefit may have risen to £1.6bn. The central estimate presented in this study should therefore be seen as a conservative estimate of winter transport benefits.

9 Science, innovation and technology

Scientific research and other innovation activities account for an important share of Met Office activities. This naturally includes the Met Office's weather and climate research, which is frequently recognised as world leading (Section 9.1). In addition to traditional weather and climate science, the Met office also undertakes scientific research and modelling related to space weather (Section 6.3.2).

Science and innovation activities also include work to collect and process observational data, develop and improve measurement systems, and a wide range of other activities (Section 9.2). These are key enablers for science. They also provide critical input without which many products and services could not be delivered.

The Met Office also works and supports the development of a range technological innovations related to weather/climate (also Section 9.2). These could be to support and develop weather/climate research, or to make it more widely available and easily accessible. An example of this is the Met Office's partnerships with leading tech organisations (see Box 22).

Box 22 Case Study: Powering Up by Partnering up[xxvi]

To do its work most efficiently and effectively, as well as to maximise its value to the UK, the Met Office collaborates with various technology partners. These partnerships can be thought of as generating two types of benefits:

1) direct (shorter-term) benefits, some of which are currently already being generated.
2) strategic (long-term) benefits supported by influence that the Met Office holds.

Although it may be tempting to try to isolate these two types, they are highly related. Strategic benefits build upon relationships stemming from direct benefits.

Direct benefits: using the cloud to make data widely accessible

The Met Office also plans to deliver value via data delivery partners. It aims to work with these partners to increase the reach of Met Office data by providing its data through delivery partners' platforms, as well as providing a service to direct data users. Delivery partners will include multinational technology companies, such as:

- Microsoft;
- Google (Alphabet);
- AWS (Amazon Web Services); and,
- ESRI (Environmental Systems Research Institute, who already distribute some Met Office data via their platform).

The Met Office aims to provide weather data to these partners[xxvii], who in turn will use their platforms to provide access to Met Office data to a broad range of users, including both large and small companies. These companies thereby benefit from being able to access the data from platforms they already use and are familiar with. Users in turn are then able to utilise Met Office data in their own products and services. Furthermore, delivery partners are able to see an aggregated view of market demand which would be difficult/ costly for the Met Office to gather themselves. In combination with the Met Office's expertise of weather data, this can guide users on which products and services would be useful in the market.

Delivery partners may also be able to provide access to Met Office data in a wider variety of formats and complexity (e.g., different slices of data depending on user needs) and do so at lower costs than the Met Office could. Interested parties can already extract custom cuts of data from the Met Office on a cost basis.[xxviii] However, delivery partners are likely to be able to maintain such a service at lower costs due to their scale, thus lowering the barrier of access to data.

Mutual benefits of this arrangement

This arrangement is mutually beneficial. The users of the data can, via platforms they already use, more easily create weather-based products without the need to find and wrangle data on the Met Office's website. This facilitates the use of weather data in new or existing products that are marketed and sold to interested market participants.[xxix] For example, a user could create innovative ways of visualising weather data, making it easier to work with. In this way these products can further improve the accessibility of Met Office data and increase its usage.

In return, the Met Office does not need to commit engineering resources to build these types of products in-house. It is difficult to monetise the precise cost and time savings resulting from partnerships. However, the Met Office has provided the following guidelines for the effort required to develop different types of projects within the Office. These suggest the potential savings resulting from partnerships are likely to be substantial.

1. A very small simple templated pdf report would require around £5,000 worth of Met Office effort.
2. Simple applications such as the Met Office's presenter app require in the region of £800,000 of development efforts and around £100,000 in running costs.
3. Large complex internal platform capability projects could very well require £10 million or more in development costs as well as over £200,000 in running costs.

Met Office staff can also access these third-party products and increase reach to new audiences, for example, in industry sectors where they do not have internal capacity to provide direct services. The development of such products will most likely be done at a lower cost and potentially be more useful than what could be developed in-house. This is because the Met Office does not have deep industry knowledge in all sectors. Therefore, tapping into this knowledge via delivery partners, who have the scale to dive deep into more sectors, is likely to result in better products overall. In addition, end-users themselves, other market participants will also have access to products developed by data delivery partners, thereby also benefitting from these partnerships.

Moreover, enabling a wider user-base to utilise Met Office data means that a wider range of products and services are developed than the Met Office could provide on its own. 'Windy', a weather forecast visualisation app, is one such example of a product developed by a user of Met Office data which has surpassed what is provided by the Met Office. The Windy app provides a different user experience and several additional features over the Met Office app. Moreover, it is already the app of choice for important Markets, for example it has many applications in Defence.

Facilitating the use of meteorological data in AI applications

In a similar fashion, the Met Office also works with delivery partners on weather-based Artificial Intelligence. This area is still in the early stages of development given the relatively nascent AI sector. The value here lies in the rich historic data that the Met Office can provide. Companies can use this rich dataset to develop models of their own. There is large scope for this area to scale significantly due to the rapid increase in companies using AI. Applications of the data will become more specific to certain use cases, whilst the variety in users is likely to expand appreciably.

Provision of rich Met Office data through existing and widely used data platforms means Met Office data can be more easily utilised in AI products by users of these platforms. Again, this is likely to facilitate usage of Met Office data in these products, thereby increasing reach of Met Office information, enabling a wider variety of AI products and services utilising meteorological information.

Strategic benefits: leveraging strategic partnerships & supporting the government's priorities on critical technologies

The Met Office is an attractive partnership proposition across the emerging technology sector for several reasons.

Firstly, the Met Office is sufficiently large to matter in the global weather market but not so large that processes within the Met Office become unwieldy and overly bureaucratic. With its status as a trading fund, it is more able to pursue private sector collaborations compared to similar government services in other countries.

The Met Office also covers the entire chain of meteorology in its remit, ranging from scientific research to information provision to the public via weather forecasts. This means that the Met Office attracts interest from technology partners with different aims from collaborations. The Met Office works with academics, international governmental bodies and private global technology companies to push the boundaries of science and technology.

Technology partnerships bring wider benefits. The Met Office can leverage substantial strategic benefits since its partnerships provide access to Big Tech companies. Through its collaborations it frequently engages with key stakeholders at Big Tech companies. It also sits on a number of Big Tech advisory councils.

These channels provide the Met Office with a degree of influence allowing it to provide input into their long-term development plan and steer the strategic direction of Big Tech development.[xxx] It can do so for its own benefit, but more importantly it can also use its channels to support the government's priorities on critical technologies such as Artificial Intelligence, science engineering[xxxi]

The development of exascale computing will vitally shape these technologies, either because exascale computing supports the development of computational-heavy technology, or because it generates demand for materials and techniques underlying computation. Development of advanced Artificial Intelligence, science engineering and digitised communication will likely be driven by exascale computing. However, providers of exascale computing will rely on cutting-edge IT technology, including innovative semiconductor technology and quantum computing, to be able to satisfy the demand for computing power.

As high-level computing power is increasingly moving to the cloud, the Met Office is uniquely positioned within government to influence the development of exascale computing in support of the government's priorities. Additionally, the Met Office has already been at the forefront of exascale computing for a number of years, working with other public sector research establishments (e.g., the UK Atomic Energy Authority). As a result, the Met Office and its partners have a strong knowledge base on the likely development of the technology in the future. AWS, Microsoft Azure and Google Cloud cover 65% of the global market share for cloud computing.[xxxii] The Met Office collaborates or has collaborated with all three. As such, it has influence to steer the direction of cloud computing, and thus exascale computing, ensuring that the UK retains access to cutting-edge physical and digital computing infrastructure.

More widely, the influence of the Met Office provides a strong signal of the UK's strengths and ambitions to Big Tech firms. By sitting on the table (often as the only British organisation), the Met Office advertises the UK as a market worth exploring by Big Tech, highlighting the UK's relevance. This will open opportunities for British companies to collaborate and partner with foreign Big Tech companies. Which is particularly relevant to the government's aim of making the UK a "science and technology superpower" by 2030.[xxxiii]

Conclusion

Technology partnerships provide mutual benefits to the Met Office, delivery partners, and data users. By partnering with Big Tech companies, partners can use their platforms to improve access to Met Office data and to facilitate the development of products and services that are available on the market. Moreover, and possibly more importantly, it can use its strategic positioning to exert influence over the long-term direction of technology development. Thereby it can support the UK government's strategic priorities in relation to key technologies and enable the UK to retain access to key computing infrastructure going forward.

Case Study References:

Information in this case study is based on consultation with the Met Office, unless stated otherwise.

[xxvii] This data is provided at cost of data provision. Cost of data creation (i.e., weather modelling) is not charged.

[xxviii] The Met Office does not charge for the data itself, as this is generated as part of its strategic National Capability. It, however, charges for services making the data available. The costs of these are not negligible.

[xxix] The Met Office benefits from this indirectly. Since products rely on Met Office data, marketing conducted by delivery partners and users also advertises the data itself.

[xxx] It can also influence operational decisions of Big Tech companies, such as where to locate a server farm, in contractual requirements.

[xxxi] Department for Science, Innovation & Technology (2023, March 6). *The UK Science and Technology Framework.* Available at: https://www.gov.uk/government/publications/uk-science-and-technology-framework/the-uk-science-and-technology-framework

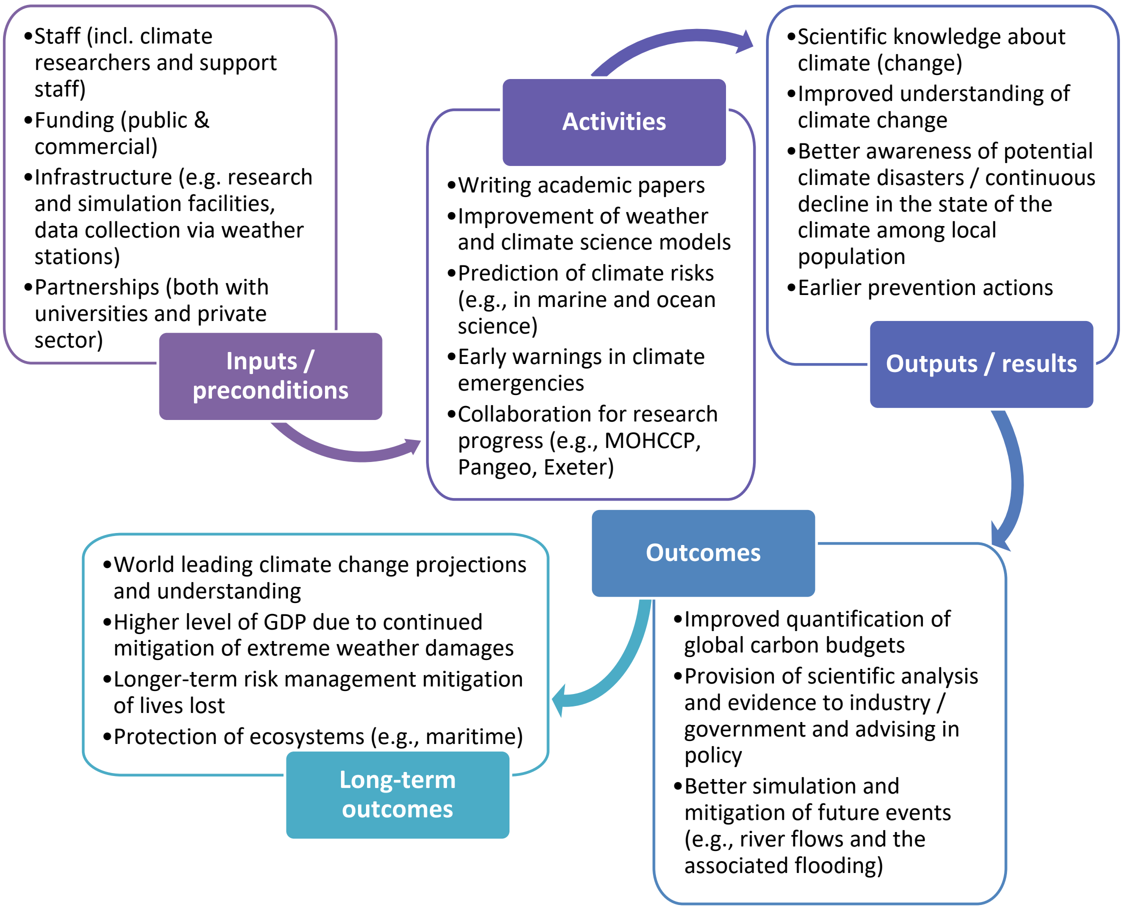
[xxxii] Statista. (2023, August 8). *Amazon Maintains Lead in the Cloud Market.* Available at: https://www.statista.com/chart/18819/worldwide-market-share-of-leading-cloud-infrastructure-service-providers

[xxxiii] Please see: https://www.gov.uk/government/news/plan-to-forge-a-better-britain-through-science-and-technology-unveiled#:~:text=The%20Prime%20Minister%20and%20Technology%20Secretary%20have%20today%20(Monday%206,talent%20to%20the%20UK%2C%20and

9.1 Weather/climate science and research

Weather/climate science and research is a key component of the Met Office's scientific and innovation activities. This includes undertaking scientific research itself, developing and improving the weather/climate prediction models, as well as developing the science and tools required to make Met Office research useful and usable for customers. The Met Office also collaborates with many research partners, including other meteorological institutions, academic partners and weather/climate-related international organisations such as the United Nations Intergovernmental Panel on Climate Change (IPCC).

Figure 12 Impact pathway: Weather/climate science and research



Source London Economics

A key part of the Met Office's climate-science activities is the Met Office Hadley Centre for Climate Science and Services (MOHC). The MOHC is one of the UK's foremost climate change research centres. Met Office Hadley Centre scientists have worked with international researchers from 2,025 institutions in 144 countries. They produced, since the Hadley Centre's founding in 1990, almost 3,200 peer-reviewed articles, which have appeared across 200 different journals, and have been cited over 310 thousand times (Met Office, n.d. b).

Scientific knowledge generation itself has wide-reaching effects by improving understanding of climate change and the means to measure and observe the weather/climate. This is essential, for example, to mitigate the risk of climate change and to better adapt to the impacts of climate change through improved adaptation measures. However, the Met Office's research and innovation activities are also a critical enabler that underpins many of the Met Office's other weather and climate related activities.

Of course, none of these impacts would be achievable without the Met Office's world-class climate scientists and researchers, public funding, the Met Office's research infrastructure, and its partnerships. Figure 12 provides further details on the key inputs, activities and benefits of the Met Office's weather and climate science and research activities.

Figure 12 further highlights the short term (output), medium term (outcome) and long-term benefits from weather/climate science and research. In the short term, the scientific knowledge created through climate research and modelling improves understanding of climate change and the quality of weather/climate models and forecasts. This enhances awareness of potential climate impacts and enables earlier mitigation and adaptation actions to be undertaken. In the medium term, this improved understanding helps policy makers, and industry, to make better decisions.

For example, carbon budgets can be better quantified which improves adaptation and mitigation measures in the medium term. In the long term, the scientific activities of the Met Office contribute to the world-leading climate projections and understanding of how the climate evolves far into the future. Moreover, the science-informed improvements in mitigation and adaptation measures lead to higher economic prosperity and welfare of future generations. Also, the marine models developed by the Met Office help to protect maritime ecosystems and improve ocean sciences.

Please note: To avoid double-counting with other benefit streams, the socioeconomic returns resulting from Met Office weather and climate science and research are not estimated separately.

9.2 Observations, data provision, and technological innovation

The Met Office has substantial infrastructure to gather observational weather and climate data. Measurement technologies range from traditional meteorological sites to satellite earth observation (EO) systems as well as weather balloon systems and the UK radar network. The Met Office also collects data on air conditions, soil, relative humidity, wind speed, atmospheric pressure, sea surface temperature, sea ice, as well as a range of other data.

The Met Office uses these datasets in its own models and forecasts. It also provides observational and other data to other organisations to use for their own research and modelling. In addition to the collection of data, Met Office activities also include activities to develop and maintain the infrastructure enabling provision of datasets (e.g., data platforms, data transport).

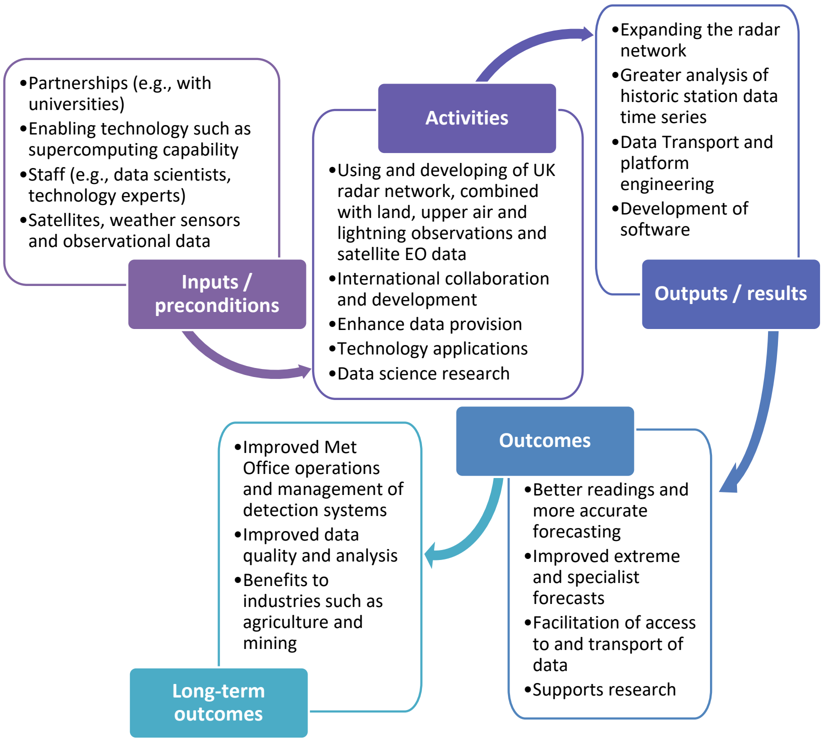
The Met Office also develops and contributes to technological innovations aimed at improving the measurement of weather/climate conditions. For example, this could be improvements in the regional and temporal resolution of weather/climate data quality. It could also improve access to existing Met office data. Innovation activities frequently occur in collaboration with universities and companies (e.g., DeepMind) or other organisations such as the European Space Agency (ESA). An example is the Met Office Climate Data Portal[26] which was built using geospatial technology from Esri UK.

In the medium term, advancements in measurement systems and improvements in data quality enhance the accuracy of different kinds of weather/climate forecast at the Met Office. For example, the provision of observational data about upper air conditions enables and improves the forecasting

[26] The Met Office Climate Data Portal can be accessed here: https://climatedataportal.metoffice.gov.uk/

of storms. The data and measurement technologies that the Met Office provides enable and support climate science more broadly. For example, they serve as inputs for numerical weather prediction models or numerical atmospheric-dispersion modelling.

Figure 13 Impact pathway: Observations, data provision, and technological innovation



Source London Economics

These activities also benefit other organisations which use Met Office data and technologies such as government departments, or industry. One key benefit to other organisations is the Met Office's access to the global observations network through the WMO and funding for international partnerships. This in turn enables the rest of the met sector, who gain access via the Met Office. For example, in the maritime sector, the Met Office delivers accessible national capability, ocean modelling infrastructure and configurations to operational and academic users through the JMMP[27]. These can then be used to improve marine models which help to protect maritime ecosystems.

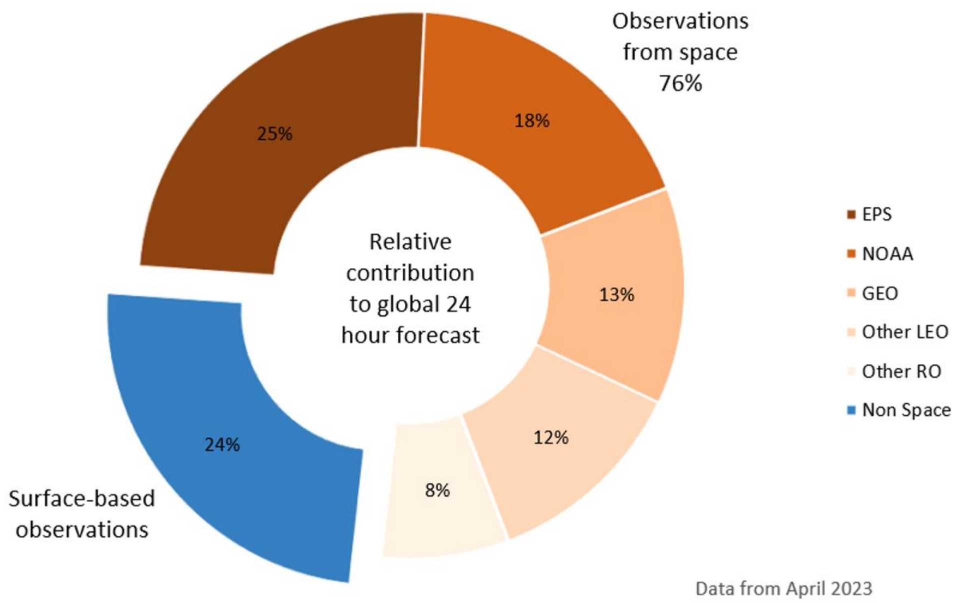
As with the Met Office scientific and research activities, this study does not monetise the benefit of the Met Office's observation data and data provision as such. This is because this would entail double counting with other benefit streams. However, observations data is a key input to other Met Office services. Indeed, without observational data the Met Office would be unable to run its meteorological models, and therefore would be unable to produce weather forecasts.

The contribution of different types of observations varies by meteorological model. Figure 14 provides a breakdown of the contribution of space- and surface-based observations to the global 24 hour forecast the Met Office provides. As can be seen in the graph, observations data from space plays a substantial role in this model, contributing around three-quarters of the forecast accuracy.

[27] The Joint Marine Modelling Programme (JMMP) is a partnership between the Met Office and British Antarctic Survey, National Oceanography Centre and Centre for Polar Observation and Modelling.

However, ground-based observations also play an important role in Met Office forecasts. Indeed, depending on the type of model their contributions is substantially larger than that implied by the global forecast breakdown below. For example, ground-based observations play a much more important role for the Met Office's regional forecasts.

Figure 14 Contribution to forecast accuracy – global 24h forecast



Note: The figure shows the relative contribution of different types of observation data to the accuracy of the global 24 hour forecast.
Source: Met Office

Box 23 Evaluation of the impact of innovation activities - commercial catalytic benefits (baseline scenario)

Approach: The Met Office's activities in the areas of science, innovation and technology are key enabling activities. As such, the benefits resulting from these activities are, at least in part, already captured in the valuation of other benefit streams. Therefore, to avoid double counting, only a narrow valuation of benefits associated with the Met Office's innovation activities is undertaken. Concretely, innovation activities undertaken are estimated using literature estimates on the social return (30% is used for the baseline estimate) deriving from the Met Office's public science investments in key commercial sectors. This strand attempts to capture the wider influence of the Met office in driving market growth through investment in new commercial products. Therefore, only sectors previously identified as likely to experience positive growth were used in the analysis. In line with the previous analysis these were offshore energy and commercial aviation.

Results: The baseline estimate for the total present benefit associated with this stream is £15 million, a relatively small proportion of the total benefit estimate but nonetheless a significant value. However, as pointed out this estimate considers only a narrow range of activities to avoid double counting with other streams. Moreover, whilst some investments into new products go on to be transformative in their impact on the economy, other deliver only marginal improvements. As such this unquantified benefit could range from small to substantial in scale.

Box 24 Case Study: Can Autonomous Vehicles take the "rains"?

In 2021, police in Great Britain recorded over 67,000 collisions for which contributing factors were known. In the majority of these, humans were at fault. Driver error, such as swerving or failing to signal, contributed to 64% of collisions, and dangerous behaviours to 25% of collisions.[xxxiv] Autonomous vehicles not requiring driver input may have avoided some of these collisions.

Beyond saving injuries, autonomous vehicles may also substantially contribute to the UK economy. The UK market for autonomous road vehicles is predicted to grow to £41.7bn by 2035, with the market for the underlying technologies contributing a further £6.4bn.[xxxv] In a similar vein, the market for drone-based services in the UK has been projected to grow to £45bn by 2030.[xxxvi] This market could include autonomously operating drones.

These examples show that Autonomous Vehicles (AV)[xxxvii] can provide substantial value to the UK economy. However, it is known that weather affects the functioning of AV in the following ways:

- weather affects how sensors function.
- weather impacts the context in which AVs need to function, with weather impacting:
  - conditions of infrastructure.
  - behaviour of other (non-autonomous) vehicles nearby.

If the full potential of AV is to be reached, potential users need to have the confidence that autonomous technology is safe. This is in line with Principle 1 of the UK government's urban strategy for the Future of Mobility: ensuring that new modes of transport are safe and secure by design.[xxxviii] As such, integrating and accounting for weather – ensuring that the technology is safe for widespread use – is critical to the development, deployment, and adoption of AV technology.

Sensing the weather

Weather affects sensors on AV. Fog changes how well cameras can see; rain decreases the use of LiDAR.[xxxix] This extends beyond inclement weather. For example, glare from the sun in clear weather can also affect sensors.[xl,xli] Recent developments to improve sensors seem to focus on two strands. Firstly, developments have been made to use a mixture of sensors ('fusing sensors') to work together under different weather conditions.[xlii] Secondly, Artificial Intelligence algorithms are being developed and improved that boost 'imaging' by the sensors.[xliii]

To aid development and testing of sensors, the Met Office – in cooperation with the National Physical Laboratory – is conducting a three-phase project to evaluate sensor performance related to weather in a traceable and quantitative way. The goal of this project is to create a framework to test and validate sensors, implemented through regulation and standards. The framework may also feed in regulators' work on authorising the use of AV. It is aimed at ensuring safety of AV, while making the framework available to everyone (rather than just to large market participants).[xliv]

There is more uncertainty regarding the direction for research beyond the 2025 horizon. The Met Office will need to be led by the requirements that regulators will put on AV. Furthermore, the commercial direction of AV development is uncertain, with different developing routes possibly requiring different testing, validation, and authorisation of sensors. For example, AV could be made more or less dependent on connecting/'talking' to nearby cars to determine whether driving conditions are safe. Different levels of 'connectedness' may ask for different testing regimes.

Adapting to weather

Beyond sensing, weather affects infrastructure and the behaviour of vehicles nearby. Weather data and forecasts may be able to alleviate some of these issues. For example, if a road-based AV knows the weather, it may be able to take appropriate control measures, such as reducing speed in a downpour.[xlv]

The Met Office currently provides weather information that can be used by AV, but not in any specialised form. It is uncertain what, if any, specialised data will need to be developed in the future. It is uncertain, for example, whether "hyper-granular" forecasts will be useful to the market. Weather can be highly variable within small timeframes, which could make such forecasts unreliable. Further commercial development will need to determine whether such data is still useful to enable AVs.[xlvi]

Moreover, uncertainty also exist regarding the different requirements for Met Office data for different types of AVs. For example, it may not always be possible to create "hyper-granular" forecasts. Whereas on land it may be feasible to build weather stations (nearly) everywhere, this is not possible at sea. As such, data enabling "hyper-granular" forecasts may not be possible for marine AV. Similarly, unreliable data may be deemed useful in road-based AV – where a car can pull over and wait for further information if systems are inaccurate – but not for aerial AVs – where pulling over is not an option.[xlvii]

Feeding back the weather

While the Met Office can provide value to the AV market, the AV market can also theoretically provide value to the Met Office. AVs carry a lot of sensors which can be used to collect weather-relevant data. For example, road-based AVs can detect fog because cameras perform differently in fog than in clear weather.[xlviii] This possibility was recognised by the Met Office as far back as 2016.[xlix] However, shortcomings of this possibility need to be considered. AVs could provide large quantities of data that may be considered outdated quickly. For example, AVs can provide data on weather conditions of a specific location very briefly as they move through the landscape. As such, the value of integrating such data in national weather predictions may not necessarily be worth the costs. Nevertheless, advanced in AI could enable the Met Office to use this data in very short range forecasting (nowcasting) which, if materialised, could benefit a range of sectors including the AV sector themselves[l]

Conclusion

Much is uncertain about the future development of Autonomous Vehicles, especially beyond the immediate future. This means the value that the Met Office can create in this domain is also uncertain. However, the potential for value generation is present. The main benefit may be that the Met Office is promptly engaging in conversations on the impact of weather on AV, so that regulators and the government can respond to new challenges sooner rather than later. This will enable multi-bn-pound AV markets for cars, drones, autonomous ship operations and others to establish themselves more quickly.

The Met Office is particularly well positioned to support this development:

- It brings specific expertise in weather, which Big Tech companies may not have.
- As a public organisation, it can devote resources to developing technologies that are accessible to all and do not aim to make a profit. This includes the testing framework

for sensors that is being developed in cooperation with the National Physical Laboratory. This sets the Met Office apart from private weather forecasters.

- Due to its structure as a Trading Fund, the Met Office tends to be relatively open to collaborate with the private sector. In contrast, similar weather services in other countries tend to be more bureaucratic and less willing to engage with the market.[li]

Due to this unique position, the Met Office can be a critical in the development of AV and underlying technologies.

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[xxxvi] PwC. (2022). Skies Without Limits v2.0. Available at: https://www.pwc.co.uk/issues/emerging-technologies/drones/the-impact-of-drones-on-the-uk-economy.html

[xxxvii] In a narrow sense, the term 'Connected and Autonomous Vehicles' often refers to (self-driving) cars. In this case study, a broader position is taken which also considers aerial and marine autonomous vehicles.

[xxxviii] Department for Transport. (2019, March). Future of Mobility: Urban Strategy. Available at: https://www.gov.uk/government/publications/future-of-mobility-urban-strategy

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[xl] Consultation with the Met Office.

[xli] In the broadest definition of weather, this also includes space weather. This affects, for example, the functioning of positioning systems such as GPS.

[xlii] See e.g. Artificial Intelligence + (2023, June 14). Can Self-Driving Cars See in Bad Weather?. Available at: https://www.aiplusinfo.com/blog/can-self-driving-cars-see-in-bad-weather/

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[xliii] See e.g. Oxford University (2022, September 8). Oxford researchers develop new AI to enable autonomous vehicles to adapt to challenging weather conditions. Available at: https://www.ox.ac.uk/news/2022-09-08-oxford-researchers-develop-new-ai-enable-autonomous-vehicles-adapt-challenging

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[xlvi] Consultation with the Met Office

[xlvii] Ibid.

[xlviii] US Department of Transportation (2016). Vehicle Automation and Weather: Challenges and Opportunities.

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Met Office (n.d.) Written evidence submitted by the Met Office (SDV0042). Available at: https://committees.parliament.uk/writtenevidence/110908/pdf/

[l] Consultation with the Met Office.

[li] Consultation with the Met Office.

10 Other key activities

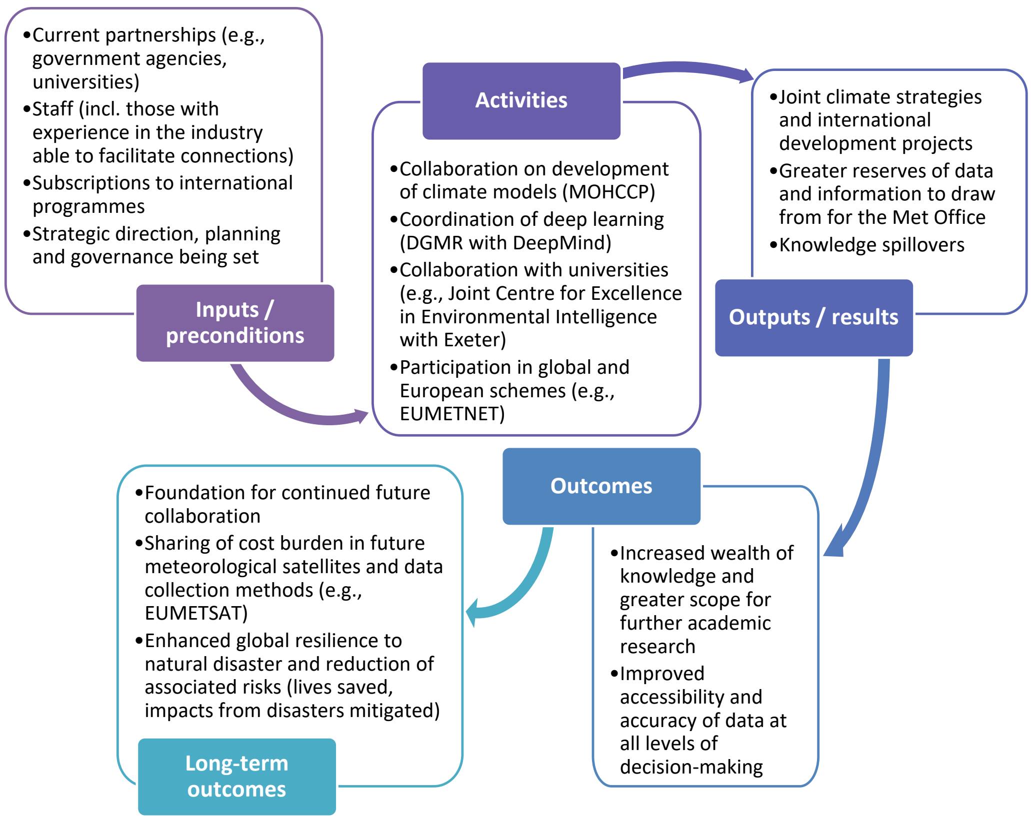
Certain activities of the Met Office cannot be classified under any of the previous sectors, but they can still deliver significant value to the UK and globally, or enable other key Met Office activities. This includes the Met Offices international partnerships and development activities (Section 10.1), its defence activities (Section 10.2), as well as other activities such as education and outreach activities (Section 10.3).

10.1 International partnerships and development

The Met Office is engaged in multiple partnerships and collaborations with universities and international organisations. In many cases, the aim of these partnerships is to exchange knowledge with other weather/climate institutions or academics at universities, and leverage research output.

In other cases, the Met Office collaborates with international organisations to contribute and share access to resources (e.g., satellite data, supercomputing capacity, etc.) and to improve their weather/climate services (or those of other meteorological agencies). This is the case in Met Office partnerships with the World Meteorological Organization (WMO), the European Centre for Medium-Range Weather Forecast (ECMWF), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and the European National Meteorological Services (EUMETNET).

Figure 15 Impact pathway: International partnerships and development



Source London Economics

The Met Office also undertakes a wide range of international assistance and development activities. This includes partnerships supporting the development of weather and climate science in countries such China, Brazil, South Africa, India, the Philippines, Indonesia, Malaysia, and Vietnam. It also includes capability development programmes aimed at helping meteorological services in developing country build or improve their disaster detection and mitigation services. While not in the scope of this study, and therefore not monetised, the benefits of the Met Office's international and development activities accruing beyond the UK, particularly those to developing countries, are very important and often substantial.

Partnerships with universities and others directly benefit the Met Office by helping improve the Met Office's quality of services and products. For example, by enabling better access to data and sharing knowledge between the Met Office and the wider scientific community. A concrete example of this is EUMETSAT, which as a member, the Met Office can source satellite observations, which significantly increase forecasting accuracy (Figure 14).

However, the most important benefits deriving from the Met Office's international activities are long-term and less tangible. They include improvements in weather/climate resilience in the UK and abroad (especially in developing countries) and the increased international standing of the Met Office as a world-leading meteorological institution.

Box 25 Evaluation of international partnerships (baseline scenario)

Estimating the value of international partnerships is difficult. The value of the Met Office's international partnerships in this study was estimated through two benefit streams. These are the direct and indirect benefits associated with the ECMWF headquarters' location in the UK and the value of Met Office science partnerships. The Met Office also participates in a number of other international partnerships. Moreover, the most important benefits are long-term and less tangible. Therefore, this estimate only captures part of the value of the Met Office's international partnerships to the UK. In addition, there are substantial benefits accruing outside of the UK which are not captured.. The benefits accruing from access to data from international partnerships are partially captured in the overall value of the Met Office.

ECMWF benefits

Approach: The benefit estimation for the Met Office's participation in international partnerships considers the impact of the ECMWF headquarters being located in the UK on the UK economy. The approach, which follows the same methodology as in the 2015 General Review, estimates the direct benefit related to direct expenses that the ECMWF makes in the UK and the indirect benefit associated with the expenses of foreign visitors to the ECMWF headquarters.

Results: The baseline present benefit estimate for the ECMWF (hosting) impact in the UK is estimated to be £0.3bn. The 90% confidence interval of the sensitivity analysis indicates that the total present benefit may be as high as £0.6bn and is unlikely to be lower than £0.1bn.

Value of science partnerships

Approach: This benefit stream captures the value of science partnerships of the Met Office. The value is based on Met Office estimates of the research gearing of a range of Met Office Science Partnerships. It followed the same approach taken in the 2015 General Review but incorporated updated information. The updated estimate was based on 123 projects where 115 (93%) of these could not have been achieved (or could not have been achieved as effectively or as quickly), without collaboration. A breakdown is provided in the methodological annex.

Results: The present benefits associated with these projects are estimated to be around £0.4 bn.

10.2 Defence services

The Met Office provides numerous services to the UK military to aid them in defence activities, ensuring operational effectiveness and better decision-making abilities. The Met Office's defence activities are outside the scope of this study. However, given their importance a brief overview is provided here, nonetheless.

Many of the Met Office's products contain direct or indirect defence applications and as such, much of what the Met Office does supports UK defence interests. For example, accurate short-term weather projections are key to effective mission planning. The Met Office provides direct services to the MoD and to other strategic partners, through key partnerships including the National Security Advisory Group, NATO, US Air Force, and the Five Eyes intelligence alliance, for example, expert advisory services helping missions to be planned more effectively, and that a tactical edge can be gained in combat scenarios. Another example is the regulatory-mandated services the Met Office provides to the aviation industry (see Section 7.1), as a result of which the Met Office is also able to provide flight safety information to the defence sector to ensure operational safety.

Met Office products and services in term benefit from the UK defence sector: Met Office high-quality short-term weather projections are part-funded by Ministry of Defence (MoD) funding and utilise existing infrastructural inputs, such as radar stations, to accurately project future weather patterns.

10.3 Other activities

The Met Office undertakes a several other activities which are not categorised explicitly in the downstream activities described in the previous sections.

This includes the both the Met Office's education and outreach activities its and communication and dissemination activities. For example, the Met Office holds a Schools Programme for 7–14-year-olds aimed at helping young people understand and prepare for the impact of weather and climate on their communities. It also regularly organises and hosts STEM events and Science Camps.

The Met Office also provides a range of press briefings and publishes observations on the weather. These activities help reduce barriers and improve common access to detailed weather information in various formats (including new formats such as social media or through a weather-related curriculum for young people), as well as increasing weather/climate understanding for the future.

Other activities, like the Natural Hazards Partnership (NHP) and the Radioactive Incident Monitoring Network (RIMNET, replaced by RREMS in 2022), focus on public sector agency collaboration for better risk management and mitigation. They utilise already existing partnerships with government and other public sector agencies, for example, to prepare contingency plans for natural hazard detection and management.

This benefits society more generally through early warning systems that limit damages, save lives and mitigate hazards and their risks. Furthermore, this allows for greater analysis of hazard data and catalyses natural hazards science, developing the interrelationship between nuclear incident transmissions and weather patterns.

The benefits of these activities, while important, are not quantified in this study.

CONCLUDING REMARKS AND REFERENCES

This part provides:

- London Economics' concluding remarks on the updated economic value of the Met Office to the UK economy.
- The list of references used in this report.
- An index of all tables, figures and boxes used throughout the report.

Image credit: Giorgio Trovato/unsplash

Conclusion

This independent evaluation study highlights the substantial benefits the Met Office's activities bring to the UK economy, society, and government. Total benefits to the UK are estimated at around £52.6bn. This implies a benefit of £18.8 accruing to the UK per £1 of public money invested in the Met Office.

The monetised central benefit estimates represent an increase of 40% (£16.0bn in 2024 prices) compared to the 2015 General Review.

Sensitivity analysis accounting for uncertainty surrounding the magnitude of benefits shows the actual benefits could plausibly be substantially larger. This suggests central valuations in this report are conservative.

Despite the conservative nature of estimates in this study, the benefit-to-cost ratio of 18.8:1 is larger than that for other evaluations of meteorological services across the world. Other studies have typically found benefit-to-cost ratios between 2:1 and 14:1. However, many of these studies have focused on specific sectors or benefits rather than the organisations' full service offering.

This study also highlights the considerable additional benefits to the UK of having a 'world leading' Met Office compared to a more 'basic' meteorological service. The additional net benefits to the UK economy of public investment in the existing Met Office relative to the 'Basic' Met Office counterfactual scenario are estimated at over £30.0bn. Therefore, the estimated benefits accruing to the UK per £1 invested in the Met Office under 'Existing' service provision are much higher (£18.8 per £1 of public money vs. £9.9 per £1 of public money invested).

In terms of sectoral impacts, the study finds that over 80% of estimated benefits are generated by four streams:

- Benefits to the aviation sector – 22.3%
- Climate change adaptation and mitigation benefits – 21.4%
- The value of provision of weather information to the public – 20.7%
- Benefits to other industry sectors (excluding aviation and winter transport) – 19.4%

The study also highlights the considerable additional benefits of the Met Office, both to the UK as well as internationally, that are not quantified. These include, for example, the reputational and soft-power benefits to the UK resulting from the Met Office's strong international standing. They also include substantial benefits to developing nations as part of the Met Office's international development work. While these activities are not quantifiable, qualitative evidence indicates that these additional non-monetised benefits, both to the UK and globally, are sizeable.

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ANNEXES

This part provides:

- A more technical annex to the Theory of Change (ToC) providing addition details on the ToC and the Met Office's production function.
- A methodological annex providing details on the evaluation approaches for all monetised benefit streams and other methodological considerations.
- The full results of the sensitivity analysis.

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Annex 1 Technical Annex to Theory of Change

A1.1 Introduction to the Theory of Change produced for this study

The development of a **conceptual model** which establishes the rationale underpinning the activities and the intended immediate effects and short and longer-term impacts of a programme is an important step in any evaluation. In many cases the conceptual model is established through the use of a logic model, providing a map of inputs, activities, outputs, outcomes and impacts. For this study a **Theory of Change (ToC) approach** was used to develop the conceptual model, going beyond simple logic modelling. Concretely, the Theory of Change of the Met Office developed for this study comprise of following three components:

- The **logic model**, which provides a high-level overview of inputs, activities, outputs, outcomes and impacts across the Met Office's activities and sectors. The logic model takes the form of a one-page graphic, providing a high-level mapping that captures the range of the Met Office's activities, and the benefits flowing from them. The logic model is useful as it provides an overview across the range of the Met Office's activities. In addition, it provides a model against which sector specific benefit streams (or impact pathways) can be placed, thus providing the overall linkage across the more detailed benefit streams, discussed below. The logic model developed for this study is provided at the end of this section (Figure 2 in Section 2.3)
- **Met Office sector or activity specific benefit flow maps** (also known as benefit chains or **impact pathways**) provide, for key downstream activities (i.e., key sectors the Met Office operates in or key customer-phasing activities), further details on the specific inputs, activities, outputs and outcomes for downstream activities and benefits. In this way, the benefit flows or impact pathways reflect pathways to change providing further detail on the relationship between the Met Office's activities and related outputs, and the benefits and impacts derived from these activities for key sectors/services. The benefit flow maps provide the link between the high-level overview provided in the logic model and the more detailed log-frame (see point three, below). Impact pathways are provided alongside the exploration of key benefit streams in Section 4.2.
- A detailed **log-frame** in the form of a long-list Excel table (provided separately to this document) listing all elements of the ToC and providing, for each element, further details such as the ToC Level (input, output, outcome, impact), the expected timeframe (e.g., short-term, medium-term, long-term), and linking ToC elements to potential indicators capturing the identified benefits and impacts. For example, an outcome or benefit might be the provision of flood warnings at a timeliness and accuracy that enables early action to save lives and mitigate damage, the corresponding indicators may be number of lives saved and property or infrastructure damage avoided.

All three components together form the Theory of Change, but with each providing a different level of abstraction, from a high-level view across the Met Office's activities (the logic model), to more detailed examination of the links between ToC elements (the benefit flows or impact pathways) to the detailed linkage to indicators (the log-frame).

In addition to these three key parts of the logic model. A production function approach is used to describe the causal relationship between inputs and outputs. The Met Office's production function is explored in Section A1.1.2.

A1.1.1 The link to the Met Office Capability Model

The Met Office has developed a capability model that groups its inputs and activities into three key *capabilities:*

- **Enabling Capability:** The key inputs and activities providing enabling capability to the *National Capability* and Met Office *Products and Services*. Enabling Capability can be thought of as the people, partnerships and infrastructure that enable the Met Office to do its job. This includes setting the strategic direction and overall governance of the Met Office, people services such as job creation and retention, providing training, the Met Office's culture, enabling technology such as computing hardware and storage, finance including public PWS funding, portfolio delivery, customer engagement, commercial activities, partnerships, existing science and other key inputs.
- **National Capability:** The key scientific and technological capability underlying the Met Office's climate and weather services, which provides data, research, platforms and expertise to its products and services. The national capability includes the observation data underpinning the Met Office's models (including traditional surface-based observations as well as satellite), pre-processing of the data to enable modelling, the Met Office's climate and meteorological models producing weather/climate predictions and projects, and the science underpinning these models as well as the platforms and activities enabling data supply.
- **Products and Services:** Includes production activities needed to translate scientific models and analysis into products, services and insights, the activities and platforms needed to deliver these services to customers, and post processing of national capability analysis and expertise needed to deliver products and services. While for the Theory of Change a distinction was made between enabling or production activities and downstream activities, products and services very much are part of and indeed encompasses downstream activities. In addition to production and delivery activities, products and services also include customer experience activities providing user insights and demand back to the national capability.

These capabilities form the *input* stage of the Theory of Change developed for the Met Office. They are represented as *inputs and enabling activities* reflecting that these capabilities capture not only inputs as usually defined in logic models but also activities.

In practice the Met Office Capability Model also captures downstream activities in its *Products and Services* category. However, for the Theory of Change it was important to distinguish between activities enabling benefits (*enabling activities*) and activities delivering benefits (*downstream activities*). Therefore, these activities were separate in the Theory of Change. However, the relationship is acknowledged through the inclusion of the *is part of* note linking Products and Services and Downstream Activities in the logic model.

A1.1.2 The Met Office's production function: the mechanisms through which inputs and enabling capabilities deliver benefits

In economic terms, the relationship between outputs (or benefits) and inputs can be thought of in terms of a production function which relates inputs and production (or enabling) activities to outputs. In economic theory, production functions are used to represent production processes. As with any model, these functions do not necessarily completely mirror every detail of real-world production process, which of course can be much more complex and nuanced, but rather to provide a simplified yet accurate as possible approximation of the production process. A range of production functions approximating different production processes are available in the economic literature.

Given the Met Office's specific reliance on its enabling capabilities, the relationship between Met Office inputs and outputs (benefits) is best thought of in terms of a **Stone-Geary production function** (developed in Geary and Roy, 1950). Like all production functions, outputs (benefits) in a Stone-Geary production function, are linked to inputs. Therefore, **increasing (reducing) inputs will also lead to increased (reduced) benefits** (though not necessarily like for like). However, unlike in other productions functions, **there exists a minimum threshold in the input quantities below which the production of outputs and realisation of benefits would not be possible**.

In mathematical terms, one can think of the output (i.e., benefits, or Utility denoted as U) as a function of inputs (q_i) over and above a minimum necessary threshold (γ_i) below which no positive benefits would be achieved:

$$U = \prod_i (q_i - \gamma_i)^{\beta_i}$$

Of course, not all inputs are equally important to deliver outputs. For example, while a building to house the Met Office's supercomputer is necessary in order to have a supercomputer and deliver benefits, a much more expensive building would not lead to substantially larger benefits. This idea is captured by the different weights (β_i) applied to the various inputs.

In simplified mathematical terms, the relationship can be thought of as a function of a number (n) of inputs over and above a minimum threshold level of inputs necessary, which linked to outputs by input specific weights:

$$Output = f\begin{pmatrix} (Input_1 \geq Minimum\ level\ of\ Input_1)\ \dots \\ (Input_n \geq Minimum\ level\ of\ Input_n), \\ Input\ specific\ weights\ relating\ inputs\ to\ outputs \end{pmatrix}$$

In the case of the Met Office, key inputs include its supercomputing capabilities, the observations employed in the models, and expert meteorological staff. While all of these are linked to outputs and benefits and an improvement in one is likely to yield an improvement in benefits (though the magnitude may differ depending on the importance of the input), without provision of a minimum level of each and of these key inputs the Met Office would be unable to provide its services, and therefore no benefits would be achievable. For example, even if the Met Office has a world-leading supercomputer and expert meteorological staff, without weather observation data the Met Office would not be able to produce forecasts.

In addition, minimum input thresholds may not be static, but could vary over time. The Met Office's supercomputing capabilities provide a good example illustrating this relationship. Investments in better supercomputing capability allow the Met Office to undertake more accurate and/or granular modelling or provide capacity enabling the development of new models therefore allowing the Met Office to deliver an increased level of benefits. Conversely, aging supercomputing capability may progressively deliver lower benefits as the capability is less and less able to keep up with modern computing requirements. However, at some point, the capability is simply unfit for purpose and therefore unusable, meaning the Met Office would not be able to run its models therefore delivering no benefits. Therefore, continued investments may not necessarily lead to higher benefits, but simply enable the Met Office to continue to deliver current levels of benefits by keeping its capabilities up to date – only investments over and above the minimum investment level necessary to ensure capabilities keep in line with minimum technological requirements would deliver benefits beyond current levels.

A1.1.3 Relationship between inputs and outputs / benefits

Annex A1.1.2 developed a theoretical framework for the relationship between inputs and outputs based on a Stone Geary Production Function. Assuming changes in inputs are above the minimum threshold required, the Stone-Geary production function can be shown to yield a linear relationship between changes in inputs and changes in outputs/benefits:

$$\Delta\text{Utility (or outputs/benefits)} \approx \Sigma(\Delta\text{Inputs x Weight})$$

This relationship is in line with the linear system assumed in the previous evaluation. However, where the previous evaluation assumed the relationship to be linear, the production function approach used in this study provides a theoretical underpinning between the mechanisms with which inputs yield outputs or benefits.

The previous evaluation identified weightings for the various factors of production, based on literature estimates and workshops with Met Office experts. These are provided in the table below.

Table 9 Input weightings

	Observation	Scientist, modellers, and forecasters	Reach capacity	Supercomputing capacity
Reach-intensive sector (value to the public) weights	25%	25%	20%	30%
Non-reach-intensive sector (aviation, winter transport and other business sectors) weights	30%	30%	10%	30%

Source: London Economics (2015)

This study's assessment is that these weightings remain valid. However, whilst accuracy continues to be important, there has been a continuing increase in importance placed on other quality measures. In particular, an increased focus on reach (who sees the Met Office forecasts) and behaviour (how does the public/industry respond to these forecasts) has been noted. This is characterised by an increased focus on ensuring weather information is easily accessible and widely used, and that the information is easily digestible and useful, thereby enabling users to effectively utilise this information to make informed decisions.

It should be noted that while these weightings have some merit as a useful conceptual model, and indeed were informed by consultations with experts at the time, they are nevertheless a simplistic representation of reality. Characterising the complex real-world relationship between outputs and inputs in precise quantitative terms is not only very difficult but also potentially misleading due to reducing these complex relationships to an overly simplistic algebraic formulation. Therefore, important investment decisions should be based on a detailed benefit to cost analysis of the specific decision, not a simplistic model conceptual model.

Annex 2 Methodological annex

A2.1 Evaluation approaches for monetised benefit streams

A2.1.1 Weather services

Provision of weather information to the public

In order to evaluate the value that the public places on Met Office weather information, a willingness-to-pay (WTP) survey was designed by London Economics and conducted by YouGov. The survey was undertaken with a representative sample of 1,002 respondents, conducted between 26th January – 2nd February 2024.

Prior to conducting the fieldwork, cognitive testing of the survey was carried out to assess respondents' understanding of the survey, including what they are being asked to value and their understanding of the payment vehicle. London Economics, in collaboration with YouGov, developed semi-structured interview guides for the cognitive interviews. YouGov then conducted 10 one-hour online interviews and provided a report on their findings. The findings informed any necessary adjustments to the survey. These modifications were reviewed and approved by the Met Office before the main fieldwork commenced.

A contingent valuation approach was chosen to estimate the average WTP for the Met Office PWS as it captures the overall value respondents attribute to the service. This method aimed to ascertain the average amount individuals would be willing to contribute annually to maintain the current Met Office PWS, compared to a situation where the Met Office no longer provides the PWS. The chosen payment vehicle was a tax contribution, which is a common vehicle used in stated preference methodologies for valuing public goods.

The format of the contingent valuation was as follows:

1. Single-bounded dichotomous choice (SBDC)

Respondents were asked whether they would be willing to pay a given tax contribution to maintain the Met Office PWS (or not contribute that amount of tax resulting in the Met Office no longer providing the PWS). The amount of tax contribution was randomised across respondents over four different levels: £8, £16, £26 and £36.

2. Double-bounded dichotomous choice (DBDC)

Following the first question, respondents were presented with a second amount and asked whether they would be willing to contribute that amount. Respondents who agreed to contribute the first amount were then offered a higher amount in this question, while those who declined to contribute the first amount were presented with a lower amount. For example, those who accepted £8 in the first question were then offered £16, and those who rejected £8 were offered £2. The first and second questions together are referred to as 'double-bounded dichotomous choice' (DBDC).

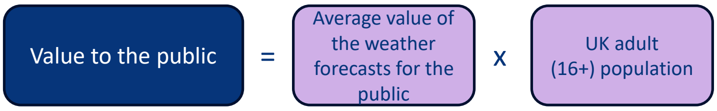
3. Bounded open-ended contingent valuation (CV)

Following the DBDC, respondents were presented with an open-response question (presented on a sliding scale). Here, they were asked to state the maximum they would be willing to contribute to maintain the Met Office PWS. The open-ended CV question was designed such that respondents were bounded by the choices they made in the DBDC to ensure consistency. For example, if a respondent rejected £8 but accepted £2, then the open-response question (and the corresponding scale) was bounded by £2 and £8.

The main result for the average WTP was calculated by computing the mean of the responses obtained from the bounded open-ended contingent valuation. This method uses the DBDC questions to establish the valuation boundaries and allows each respondent to give a precise value on their WTP.

The average WTP figure per individual was then multiplied by the UK adult population to derive the total value to the UK public, as depicted in Figure 16.

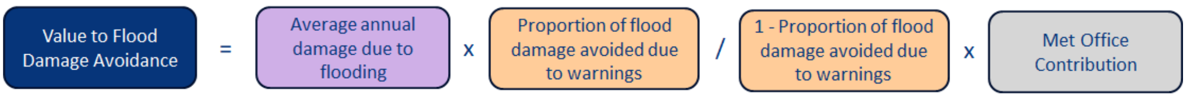
Figure 16 Benefit stream for the value to the public



Flood damage avoided

A value chain analysis approach was used to estimate the value of flood damage avoided, as depicted in Figure 17. This method is similar to that used in the 2015 General Review, however the current method accounts for a wider range of damages (i.e. including vehicle damage and emergency services as well as health and welfare) and also accounts for change in the incidence of flooding in the UK over time.

Figure 17 Benefit stream for the value of flood damage prevention



<u>Average annual damage avoided due to flooding</u>

Desk-based review of recent data identified a number of estimates of the annual average flood damage to the UK. These are provided in Table 10.

Table 10 Annual average flood damage estimates

Source	Annual average flood damage estimate	Estimates in 2024 prices
ABI and FloodRe (2021)	£958m	£1,056m
Bates et al. (2020)	£730m	£803m
ABI data referenced in Bates et al. (2020)	£714m	£785m
Environment Agency (2019)	£333m	£389m
Environment Agency (2018)	£1,300bn	£1,550m
Environmental Agency (2016)	£1,600bn	£1,976m
Average	**£939m**	**£1,093m**

Source: London Economics

One recent study by Bates et al (2021) estimated the annual average UK flood damages at £730 million. This is based on a climate-conditioned catastrophe flood model for the UK. The model estimates annual financial losses due to fluvial, pluvial and coastal flooding for residential and non-residential properties in Great Britain.

The annual average damage figure of £730 million is comparable to latest data from the Association of British Insurers (£714 million) which represents total financial losses due to flooding, although this does not account for insurers who are not members of the ABI or for underinsurance of households. More recent estimates by ABI and Flood Re (2021) suggest somewhat higher damages of £958m.

The Environment Agency also publishes its own flood damage estimates. However, these vary substantially by year, depending on the incidence of flooding occurring in that year.

Analysis undertaken for this study uses the average flood damage estimate across all data point identified (£1.1bn in 2024 prices) for the central valuations. The lowest estimate (£333m or £389m in 2024 prices) is used as the lower bound in the sensitivity analysis.

A higher value of £3.2bn (£4.0bn in 2024 prices) was used in the previous 2015 General Review. This higher estimate was previously provided by the Environment Agency and was used in its flood benefit modelling at the time. The flood benefits model is due to be updated in future, and so this assumption may change.

Given recent literature evidence, and in line with the decision to err on the side of caution, it was decided to use the lower value for the central case. Nevertheless, it is important to acknowledge that benefits may indeed be higher than indicated by current research. For example, the lower damage figures could be the result of better forecasting and mitigation meaning more damage is prevented. Therefore, the higher figure is used as the upper bound in the sensitivity analysis as the official value.

Uplifts applied to estimates of flood damage avoided

In the 2015 General Review, a 50% uplift on annual average flood damage was applied to account for intangible benefits related to health and wellbeing. In this study, updated uplifts from JBA Consulting (2018) in Ross (2019d) are applied, which suggests a figure of 28% (see Figure 18 below).

To account for the increase incidence of flooding in the UK, figures based on a study by Cotterill et al. (2021) are used. The study estimates that extreme daily rainfall totals in excess of 50mm per day on a UK wide scale is expected to increase by 85% between 2019 and 2080, an average increase of 1.4% per year.

Figure 18 Applied uplifts in JBA Consulting (2018) in Ross (2019d)

Description	Applied benefit
Vehicle Damage	10.3% uplift to property damages
Health and Wellbeing	12.3% uplift to property damages
Emergency Services	5.6% uplift to property damages

Proportion of flood damage avoided due to warnings

In line with the 2015 General Review, this study estimates that between 6% to 10% of flood damage is avoided through flood warning systems. As mentioned in the discussion on average annual flood damages, it is likely that improvements in forecasting and mitigation measures mean that more damage is avoided than implied by this assumption.

Unfortunately, no new evidence on flood warning effectiveness rate could be found for this study, however the assumptions were tested with various stakeholders, including the Environment Agency.

In 2015, the Flood Warning Response and Benefits Pathways (FWRBP) model was developed by the Environment Agency and converted into a spreadsheet tool called the ANSR (non-structural responses) framework. Ross (2019d) proposes a methodology for estimating the proportion of flood damage avoided due to warnings (and quantifying the value of flood damage avoidance) using estimates from the Environment Agency (2015).

The study proposed to, if possible, sense-check estimates for flood damage avoided with the Environment Agency's estimate from their FWRBP model. On consultation with Environment Agency, their most recent version of the ANSR spreadsheet tool indicates total avoided damage figures in line with this study's estimates, which suggests 6 to 10% remains a reasonable assumption.

Nevertheless, to account for some changes in quality the assumptions on future quality improvements (see Annex A2.4) were applied to the central assumption used in the previous 2015 General Review. This suggested a starting value for the proportion of flood damage avoided of just over 9%, i.e., at the upper end of the previous reasonable range.

<u>Met Office contribution</u>

The 2015 Met Office review assumed a 25% contribution of the Met Office to the flood warning service. This assumption was based on estimates from PA (2007) and as such is now many years out of date. It is possible that the share of benefits that should be attributed to the Met Office has involved over this time, for example, due to the important role the Met Office plays in the Flood Forecasting Centre (FFC) which is operated in partnership with the Environment Agency. The FFC was established in 2007 and so would not have been captured in the original PA (2007) estimates.

However, making assumptions on attribution is difficult and involves best judgment. As no new robust evidence to warrant a change to the attribution figure has been identified, a 25% contribution was again assumed for this study. Consultations with Met Office staff as well as the Environment Agency undertaken as part of this study sought to verify the 25% figure. While not conclusive, these suggested that this figure is still a broadly sensible assumption for the Met Office's contribution to the effectiveness of flood warnings.

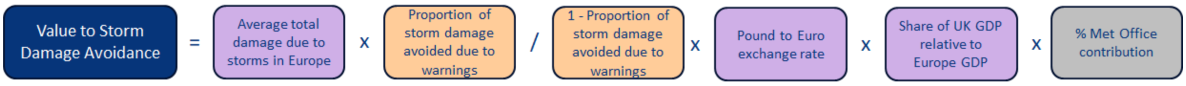
This attribution figure also aligns with the assumption made in the more recent Ross (2019d) study. This study assumes the Met Office can impact flood warning accuracy, the response uptake from the public due to having more trust and confidence in flood warnings and the operation of their response, as more people have sufficient time to operate measures effectively. It is assumed in Ross (2019d) that Met Office services are attributed to 25% of the proportionate value of warning accuracy and response operated for all warning-dependent pathways. Storm damage avoided

Nevertheless, to reflect the uncertainties surrounding attribution a 50% uncertainty range (i.e., 12.50% - 37.50%) was used around the central 25% assumption in the sensitivity analysis.

Storm damage avoided

A value chain analysis approach, similar to the approach used for valuing flood damage avoided, was used to estimate the value of storm damage avoided (Figure 19). This method is similar to that used in the 2015 General Review, however a wider range of damages (i.e. including vehicle damage and emergency services as well as health and welfare) are considered in this study. These were not accounted for in the 2015 General Review, which estimates only economic damages.

Figure 19 Benefit stream for the value of storm damage prevention



Average total damage due to storms in Europe:

A desk-based review was conducted to find an updated estimate for average annual damage caused by storms in the UK. While a reliable figure could not be found for the UK, the World Meteorological Organisation provide a total figure for Europe of $2.25bn on average per year (between 2010 and 2019, in 2020 prices). This total figure for Europe is apportioned to the UK using the UK's proportion of GDP relative to total European GDP (using data for 2022, the most recent available data at the time of modelling). Converting into GBP, this is equivalent to approximately £384 million in storm damages annually in the UK on average. To sense check this figure, it is compared to recent data on total insured losses from storms in the UK. For example, insured losses from Storm Dudley, Eunice and Franklin in 2022 amounted to £467 million (ABI, 2022). Insured losses from Storm Christoph in 2021 were estimated to be around £100 million, and Storms Ciara, Dennis and Jorge in 2020 amounted to £543 million (ABI, 2022). The average from these three estimates is equal to £380 million, and hence in line with this study's European-based estimate.

The same uplifts as for avoided flood damage are applied, as given in Figure 18. There is currently no evidence that climate change is affecting storms, therefore this analysis does not account for changes in the occurrence of storms in the future (Met Office, n.d c).

Proportion of storm damage avoided due to warnings:

The study estimates the proportion of storm damage avoided due to storm warnings to be 20%. This is based on a EUMETSAT study in 2014 which assumed that weather warnings could reduce losses by 10-50%. The 2015 study used a conservative estimate of 20% based on this range. An updated figure for this study was not found, however consultations with experts suggested this assumption was still reasonable. A 2019 study by the Global Center for Adaptation estimates that a weather warning system can reduce damage by 30% (GCA, 2019). While this study is not in the UK-context, it provides some assurance in line with the estimate utilised in this study.

Met Office contribution

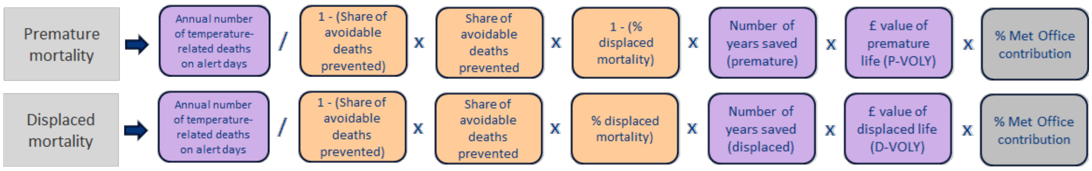
In order to attribute a share of avoided storm damages to the Met Office, the same assumption that is used for its contribution to early warning systems for flooding (25%) is applied here.

Extreme temperature alerts

The approach to estimate the value of lives saved from heatwave and cold weather alerts for this study was based on a previous study conducted by London Economics in 2019. Following London Economics (2019) an avoided loss/cost approach is employed to estimate the number of deaths avoided due to heatwave and cold weather alerts. To calculate the monetary value of lives saved, the value was then multiplied by the economic value of a life.

This approach distinguishes between premature deaths (deaths of otherwise healthy individuals) and displaced deaths (deaths of individuals who would have died relatively soon independent of external causes), following Chiabai et al. (2018) (Figure 20).

Figure 20 Benefit stream for the value of lives saved from extreme temperatures (2019)



In London Economics (2019), the annual number of temperature related deaths (on temperature alert days) were sourced from the ONS and the Met Office. The annual number of related deaths (on temperature alert days) calculated for the 2019 study is used, with uplifts applied based on several assumptions. The population of at-risk individuals is assumed to grow in proportion to the population aged 65 and above. Population projection estimates (by age band) are obtained from the Office for National Statistics (ONS). The frequency of both extreme heat and cold events is assumed to increase by a constant annual growth of 0.29%, in line with London Economics (2019). The share of avoidable deaths prevented was based on a midpoint estimate drawn from estimates in academic literature, which ranged from 9% (Morabito et al., 2012) and 81% (Ebi et al., 2004). 41% is used as an assumption for the 'effectiveness ratio' of temperature alerts, consistent with London Economics (2019). It is necessary to first adjust the number of observed temperature-related deaths by dividing by (1- the share of deaths that can be prevented by an effective heatwave or cold weather warning system) in order to obtain an estimate of the number of temperature-related deaths that would be observed in the absence of such warning systems. This is to take account of the fact that the impact of those warning systems is already reflected in the number of observed temperature-related deaths.

The percentage of displaced mortality and the average number of life years saved were taken from the Chiabai et al. (2018) study. The Met Office contribution was estimated to be 16.9%, which was based on expert advice from the Met Office. In consultation with the Met Office for this study, it was advised that this assumption was still reasonable.

To estimate the monetary value of lives saved, different average £-values per life saved for premature and displaced deaths are used, these values are £39,033 and £10,284, respectively. It is worth noting that the value per (premature) life year used in this study's estimations is considerably lower than the monetary value for a statistical life year proposed in HM Treasury's Green Book. The reason for this is that the Green Book estimate[28] includes both the value of an additional life year to the individual in question themselves (based on willingness-to-pay estimates) as well as the value to society in terms of the economic output produced by that individual during the additional life years gained. Since the Met Office alerts tend to help avoid the premature and displaced death of primarily the elderly population, the analysis does not take account of any potential gains in

[28] The estimate reported in the Green Book is based on the monetary value of a life year developed by the Department for Transport (DfT) for its transport appraisals. The DfT provides one single estimate of the value of a life across all ages (£1.9 million), and the value of a life year is obtained by dividing the overall estimate by half the life expectancy of the UK population. As noted in the main text, the DfT's estimate includes not only the value of a life year saved to the individual itself but also the loss in economic output produced by that individual.

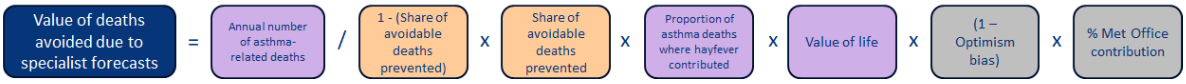
economic output, assuming that a large share of at-risk individuals has already reached retirement age. For this reason, the more conservative estimates used in London Economics (2019) are again used in this study.

Specific adjustments for optimism bias of 20% are also applied, as consistent with London Economics (2019) and the 2015 General Review.

Specialist forecasts

The approach to estimating the value of lives saved from specialist forecasts following a value chain analysis approach. In this study, the value of pollen forecasts is estimated specifically due to availability of data. The 2015 General Review evaluated the value of avoided deaths due to air quality information published by the Met Office, however due to a lack of data and evidence to support assumptions around deaths related to air quality, this study focuses on pollen forecasts and its relation to asthma-related deaths linked to hay fever (Figure 21).

Figure 21 Benefit stream for the value of lives saved from specialist forecasts



An estimate for the years of lives lost due to asthma is taken from data from NHS England (2018). Hay fever is assumed to contribute to 15% of asthma deaths, based on an estimate from the National Review of Asthma Deaths by Royal College of Physicians (2014). Due to a lack of evidence on the share of avoidable deaths from specialist forecasts, the lower bound estimate from the academic literature is applied to the share of avoidable deaths due to extreme temperature alerts. While this is not accurate to specialist forecasts, a conservative approach is taken by applying the lowest estimate of 9% to account for the uncertainty.

For the value of life, the value for premature mortality is applied, as asthma-related deaths are considered to be relatively less age-related than deaths caused by extreme temperature, and thus deaths are more likely to be premature. For the contribution to the Met Office, an estimate of 50% is used. This is based on the Met Office being one of the only organisations to produce and publish pollen forecasts. Specific adjustments for optimism bias of 20% are again applied, as consistent with London Economics (2019) and the 2015 General Review.

A2.1.2 Approach to evaluate the value of lives saved due to weather services

This study used an 'avoided loss approach' to quantity the value of lives saved as a result of the Met Office's contribution to early-warning systems for extreme weather events. The approach used was based on the methodology developed by London Economics (2019). In this study, the methodology was applied to evaluate the value of lives saved during periods of extreme heat, cold weather, and pollen forecasts issued by the Met Office.

Due to a lack of sufficient data for other types of extreme weather, such as flooding and storms, the methodology could not be applied to evaluate those cases in this study. Nevertheless, given sufficient data on the number of weather-related deaths and relevant input regarding certain assumptions (i.e. the share of avoidable deaths prevented (or the 'effectiveness rate') of early-warning systems in relation to lives saved, and the contribution of the Met Office to these systems, this methodology could be applied to evaluate the value of lives saved with regards to other extreme weather events.

Number of weather-related deaths

In absence of readily available public data, the number of heatwave and cold weather-induced deaths were estimated by combining daily mortality data from the Office for National Statistics (ONS) with Met Office alert data (London Economics, 2019). The number of cold weather (heatwave) related deaths were estimated by subtracting the average daily number of observed deaths during winter (summer) days for which no alert was issued from the average number of daily deaths during winter (summer) for which an alert was issued. The difference in those average mortality rates is attributed to the health impacts of extreme temperatures.

Other approaches found in the literature include econometric approaches such as using multiple regression analyses. For example, Ebi et al. (2004) and Chau et al. (2009) use multiple linear regression models to compare daily excess mortality between heatwave days with and without alerts issued, controlling for a range of weather and season-related variables.

Another common estimation strategy involves comparing expected and observed mortality. Fouillet et al. (2008) and Morabito et al. (2012) use regression models to estimate the relationship between daily summer temperature fluctuations and mortality prior to 2003, the year after many heatwave response plans were established across Europe. They then use the resulting coefficient estimates as well as observed temperature data to predict the number of expected deaths for the period after 2003, and attribute the difference to the implementation of the heatwave plans.

Deaths caused by other extreme weather events such as flooding and storms may be more easily identifiable, should the data exist, due to the nature of these events. However, estimating deaths related to prolonged weather events, such as a drought, may follow a similar methodology to that used in this study and London Economics (2019).

Share of avoidable deaths

Many of the 'effectiveness rates' of extreme weather warning that are used in studies which estimate the number of lives saved due to the warnings, are based on an analysis of case studies of extreme weather events. For example, the difference in expected and observed mortality in Fouillet et al. (2008) which was attributed to the implementation of a heatwave warning system in 2003 in Europe was used as an 'expected effectiveness rate' in several studies. Similarly, the 'effectiveness rate' used in the 2015 General Study used an estimate based on the implementation of a heatwave warning system in Philadelphia in 1995.

London Economics (2019) used a mid-point estimate from the 'effectiveness rates' found in the literature. However, the majority of the literature relates to extreme heat or cold temperatures, therefore there is currently a lack of data on other extreme weather events to make robust assumptions on the share of avoided deaths.

Assigning a monetary value to the number of lives saved:

Assigning the monetary value to a life saved is conceptually difficult. Common approaches to valuing lives saved include the value of statistical life method (VSL) and the value of a life year (VOLY). Both have been applied in weather and climate services, such as in assessments of the avoided deaths from early heat warning systems (Ebi et al., 2004, Burgess et al., 2014, Chiabai et al., 2018), including this study. The VSL method uses contingent valuation to assess individual willingness to pay (WTP) for small reductions in the risk of dying. The VOLY uses WTP for increasing life expectancy by one year. Other valuation approaches include Quality Adjusted Life Years (QALY), which is commonly used in cost-benefit analyses, and Disability-Adjusted Life Years (DALY), which are less often used in the UK.

A2.1.3 Climate services

The value of climate services is evaluated through the reduction in climate damages and related costs as a result of having better climate information available earlier, allowing for earlier mitigation and adaptation activity. This section presents an overview of the approach employed to estimate the monetary value of climate science conducted within the Met Office. This approach is based on the Evaluation of the 2018-2021 Hadley Centre Climate Programme (hereafter referred to as the HCCP evaluation) currently being undertaken by London Economics.

The HCCP evaluation reviewed available literature evidence on the value of climate information to i) updating emission targets, ii) supporting mitigation measures, and iii) supporting adaptation measures. Based on this evidence the study estimates likely minimum benefits attributable to the Hadley Centre Climate Programme 2018-21 (HCCP 18-21). Given the work undertaken for the Hadley Centre Evaluation, the current study does not directly estimate climate benefits to avoid duplication of work. Instead, the estimates from the HCCP evaluation, which represent the value of climate science for 2018-2021, have been scaled up to be representative of this study's evaluation period (10 years). It should also be noted that while much of climate research within the Met Office is conducted within the HCCP, this value will not be representative of all climate research and activity within the Met Office. This estimate is therefore considered conservative.

The HCCP evaluation developed models based on five different academic articles and Met Office reports were developed to obtain a range of estimates. However, these models do not estimate the total value of the HCCP and have therefore been grouped into three categories that represent distinct benefits without overlaps. Models within each category estimate the value of overlapping and sometimes identical benefits. A more detailed discussion of the underlying academic studies, the modelling steps, how the estimates were transformed for this study and the limitations can be found in the HCCP evaluation.

Table 11 provides an overview of the modelling results of the HCCP evaluation and the papers on which they are based. For this study, the mean figure is used as the central value of climate research in the Met Office. The median value from the HCCP evaluation is considered a conservative lower bound. The high figures implied by the model based on Watkiss et al. (2022) are considered an upper bound. The use of truncated normal distribution with a most likely estimate centred on the central estimate places lower value on the extreme figure based on Watkiss et al. (2022), while retaining the possibility that the benefits may indeed potentially be this large.

Table 11 Monetary estimates for the value of the 2018-21 HCCP programme

Value of …	Model	Based on	Value attributable to the 2018-21 HCCP programme	Scaled up to research over 2024-2033
… information updating emission targets	1	Hope (2013)	£113 m	£376 m
	2	Dessens and Brierley (2019)	£130 m	£433 m
	Average		*£121 m*	*£405 m*
	3	Hope (2013)	£3,580 m	£11,934 m

… information supporting mitigation measures	4	Rising et al. (2022)	£3,625 m	£12,085 m
	Average		*£3,603 m*	*£12,009 m*
… information supporting adaptation measures	5	Dawson et al. (2018)	£237 m	£790 m
	6	Watkiss et al. (2022)	£28,310 m	£94,367 m
	Average		*£14,273 m*	*£47,578 m*
Average	**1-6**		**£5,999 m**	**£19,997 m**
Median	**1-6**		**£1,908 m**	**£6,362 m**

Note: The blue shading identifies the central values used in this study; the green shading highlights the likely minimum benefit used as a lower bound, while the orange shading highlights the assumed maximum benefit used as an upper bound.

Source: London Economics (2024) Evaluation of the 2018-2021 Hadley Centre Climate Programme

A2.1.4 Industry benefits

Provision of weather information on industry

To estimate the value of the provision of weather information by the Met Office to industry the method proposed by Ross (2019a) was followed. This method improves upon the method used in the 2015 study by taking into account the behavioural response of users (i.e., what do businesses do with the information provided). The method relies on a value chain approach which is depicted in the figure below.

Figure 22 Evaluation framework for estimating the benefit to other business sectors

Source: London Economics

<u>GDP and sector share</u>

UK GDP and UK GVA by sector was retrieved from the Office for National Statistics in current prices. The sector share of GDP was calculated by dividing GVA for all industries by sector GVA (note that GVA for all industries is lower than overall GDP as not all GVA can be attributed to a sector).

<u>Weather sensitive GVA</u>

Most if not all sectors of the economy are to some degree impacted by changes in the climate and weather. Lazo et al. (2011) provide estimates of the weather sensitivity of different sectors in the United States. Using 70 years of historical weather observations, the authors examined the extent of inter-annual variation in economic activity attributable to climate variability. Climate sensitivities range from 14.4% for the mining sector to 2.3% for the retail trade sector.

Ross uses the Lazo et al. estimates for the majority of sectors, except for several (agriculture, construction, accommodation & food services, and wholesale, retails & motor vehicles) where data from a business survey administered to SMEs by B2B International, commissioned by the Met Office in 2018. Respondents were asked to estimate the potential cost saving as a percentage of annual revenue in various ranges, the resulting percentages all fell within the range of the estimates from

Lazo et al. For the purpose of this analysis, Ross's approach of using the survey data for those relevant sectors was followed, and otherwise using the sensitivities from Lazo et al.

It should be noted that these sensitivity estimates may underestimate sectors' sensitivities to climate variability going forward, as climate change results in higher frequency and severity of extreme weather.

Avoidable impacts of weather

Weather forecasts can allow firms to limit the impact of weather by preparing for extreme weather events, investing in appropriate infrastructure, and managing daily operations in a way that is consistent with weather forecasts. Based on the assumption made by Ross (2019a), around 20% of damage from weather is avoidable through the use of weather forecasts.

Reach and response factor

Firms' ability to mitigate weather impacts on their operations will depend on the accuracy of the weather forecast, the level of engagement of firms with the weather forecasts and their resulting actions, as well as the effectiveness of the actions that were taken. The accuracy of the weather forecast is based on objective Met Office verification statistics for a 'basket' of parameters at 2-3 day lead time. In 2019, forecast accuracy was estimated to be 84.9%. Values for the level of awareness of the impact of weather on firms as well as the resulting actions taken by firms are based on the aforementioned survey of UK SMEs.

The actions that individuals take to prepare for weather variability may vary in terms of their effectiveness. The approach suggested by Ross (2019a) assumes an efficacy rate of 50%, meaning that actions taken to prepare for adverse weather are on average able to mitigate 50% of the impacts. This assumption is used in the Environmental Agency's Flood Warning Benefit Response Pathway Model (2015) to estimate the average success of flood mitigation measures.

Using the assumptions described above, the overall reach and response factor is estimated to be 18.8% (see calculations in table below).

Attribution to Met Office

Finally, while the Met Office is the UK's national weather service, it is not the only weather service that UK businesses get weather information from. The total attribution of the Met Office depends on the direct market share of the Met Office (i.e., the proportion of the market that accesses weather information through Met Office channels), as well as the contribution of the Met Office to third-party providers. While Met Office staff are generally aware of which third-party providers receive Met Office data, the nature of how the third-party providers use this data is not normally known as it is commercially sensitive. The market share of the Met Office is estimated to be 30%, and its contribution to third-party services is assumed to be around 20% by Ross (2019b).

Avoidance of double counting

To avoid double counting with the other industry benefit streams, only benefits for sectors where benefits were not directly estimated were evaluated. These include the finance, insurance and real estate sectors (to avoid overlap with extreme weather warnings), transportation and storage (to avoid overlap with winter transport and aviation benefits), and public administration and defence (as defence is out of scope and public sector benefits are captured in other streams).

Model inputs	Value	Source
Impact avoidable with forecast information	***20%***	Ross (2019a)
Overall reach and response factor	***18.8%***	**Calculation: 84.9% x 85% x 52% x 50%**
Forecast accuracy	84.9%	Met Office
Impact users aware of forecasts	85.0%	B2B International (2018)
Aware impacted users who respond	52.0%	B2B International (2018)
Effectiveness of response (% damages avoided due to action taken)	50.0%	Environmental Agency (2015).
Attribution to Met Office	***44.0%***	**Calculation: 30% + (100% - 30%) x 20%**
Market share of direct Met Office services	30.0%	Ross (2019b)
Likely contribution of Met Office data in third-party provided services	20.0%	Ross (2019b)

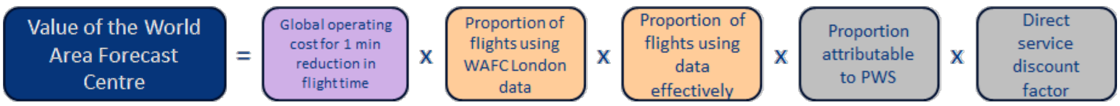
Source: Adapted from Ross (2019a)

Aviation

To estimate the value of the Met Office services to the aviation industry, the 2015 study estimated the international benefits from reducing flight times due to the World Area Forecast Centres (WAFC) using a market-based estimate approach and the national benefits of prevented costs from weather effects at UK airports using an avoided cost approach. The same approach is adopted for this study.

The value chain (Figure 23) used to estimate the benefits of the WAFC is based on the method used by PA Consulting (2007). The global operating cost for a one-minute reduction in flight time was taken from the International Air Transport Association (IATA) which estimated the average operating cost per in-flight minute to be £50. The proportion of flights using WAFC London data is assumed to be 60%, which is an assumption taken from the area of the globe that was covered by WAFC London. The proportion of flights using data effectively to reduce flight times is assumed to be 50%. The estimate of the proportion attributable to the Met Office PWS is 25%, which is based on being one of four inputs for flight efficiency. A direct service discount factor of 90.24% was also applied to take into account the CAA’s direct service spend. As the value of WAFC considers global flights benefitting from WAFC London data, the benefit is an international benefit and some of it will accrue outside the UK.

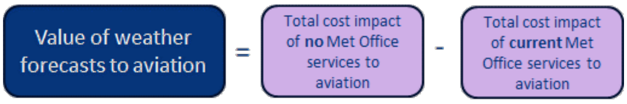
Figure 23 Benefit stream for the value of the WAFC



The prevented costs from weather effects at airports (or the value of weather forecasts to aviation) are estimated based on a study by Helios (2014). The Helios study examined weather impacts at airports due to low visibility, snow, strong winds, thunderstorms, cloud and ice. The costs were calculated for planned and unplanned responses, along with the cost of mitigation measures when a weather forecast would trigger a planned response, at five airports in the UK: Heathrow, Stansted, Glasgow, Exeter and Norwich. Using data from the Met Office for the occurrence of these events, the study employed a Cost-Loss model to calculate the benefits of Met Office forecasts for these weather impact events for the five airports. This was then scaled up to account for all UK airports.

The scenarios of interest (and used in this study) are: baseline scenario (all costs are for unplanned responses) and the baseline scenario (current Met Office accuracy for hit rates and false alarms). For the baseline scenario the total cost impacts for 2012 were calculated as £1,472m. For the baseline case the total cost impacts for 2012 were calculated as £797m.

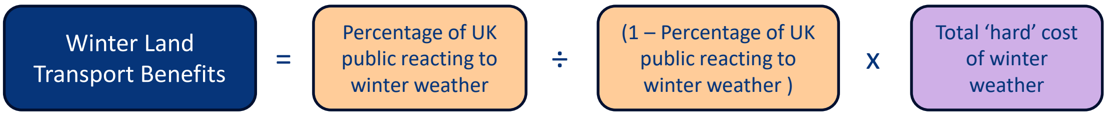
Figure 24 Benefit stream for the value of weather forecasts to aviation



Winter transport benefits

The Winter Resilience Review Panel (2010) estimated the hard costs of winter weather (road and pedestrian accidents, lost economic output due to different kinds of delays) to be £450 million per annum. This figure does not include the costs that are avoided, and it is plausible to assume that it would be significantly higher in the absence of the Met Office weather forecast. In order to estimate the winter transport benefits of the Met Office, the hard costs that are avoided because people and organisations adapt their behaviour to the weather forecast/warning needs to be quantified. Nurmi et al. (2013) assume the percentage of the UK public who reacted to winter weather information to be 14%. This percentage and the hard costs of winter weather can be combined, as shown in Figure 25, to obtain the avoided winter weather costs due to the Met Office, which are regarded as the winter land transport benefits. This was also the methodology used in the previous evaluation of the Met Office by London Economics in 2015.

Figure 25 Evaluation framework for estimating the UK winter transport benefits



Source: London Economics

Unfortunately, an updated figure for all the hard costs of winter weather was not found. However, the Department for Transport (DfT, n.d.) releases data on the number of winter-weather-related road accidents in the UK. Moreover, Transport Scotland (n.d.) released data (in 2020 prices) on the costs per accident, by type of costs (e.g., material damage, insurance) and level of severity. The data on the number of accidents and the costs per accident were used to estimate the £-costs associated with excess road accidents from the DfT road accident data. Hence, an alternative estimate of the road accident component of the hard costs was calculated using this data. This estimate provides a comparison with the methodology from the General Review and further contextualises the benefit estimate.

A2.1.5 Other benefits evaluated

Space weather benefits

In order to estimate the socioeconomic impact of the Met Office's space-weather related activities, an avoided-cost approach was adopted to estimate the space-weather related costs that would have arisen in the absence of space weather forecasts.

Oughton et al. (2019) provide an estimate of the socioeconomic impact of critical electricity transmission infrastructure failure from geomagnetic disturbance due to a 1-in-100-year space-weather storm on the UK alone. In the absence of forecasting capabilities, the impact increases from £2.9bn to £15.9bn, meaning that the impact of the forecasting capabilities in avoiding the costs is £13bn. The paper also provides similar figures for a 1-in-30-year event (£1.9bn GDP impact decreasing to £0.4bn under current forecast) and a 1-in-10-year event (impact of £0.4bn with no forecast).

Based on these estimates, the analysis therefore assumes that each year there is a 1-in-10 chance to incur £0.4bn of space weather associated damages, a 1-in-30 chance of £1.5bn damages, and a 1-in-100 chance of £12.9bn damages. This results in annual expected damages of around £220 million (in 2019 prices). Note, that in practice no damages would occur for a period of years with higher damages occurring at some unknown point.

In order to attribute benefits to the Met Office, assumptions on the share of benefits attributable to the Met Office's through its contribution to the provision of the space-weather forecasting capabilities had to be made. This is an important element to isolate the additionality of the impact of space-weather forecasting capabilities which is attributable to the Met Office. To date, sufficient evidence to enable a robust assumption to be made has not been identified.

In the absence of robust literature evidence, the Met Office's role in three key areas required to enable avoidance of space weather impact was considered:

- **Data collection, provision of sensors, and satellites:** The Met Office does not currently operate satellites collecting space weather information. Instead, this data is obtained via bilateral agreements with NOAA and NASA, as well as, to a lesser degree, via EUMETSAT. EUMETSAT currently only provides limited amounts of space weather observations data. However, in future EUMETSAT is expected to have more space satellite data itself. Moreover, the collaboration with NASA and other partners are expected to run via EUMETSAT in future. A 0% contribution of the Met Office as a lower bound is assumed. As a maximum attribution access to space data in future is assumed to run via EUMETSAT. The maximum attribution was therefore set to the Met Office's contribution to EUMETSAT relative to other contributions (currently around 13%). As a central assumption it was assumed that neither the Met Office nor EUMETSAT contribute substantially to the data collection-aspect. However, a small (5%) share was attributed to the Met Office taking into account the Met Office's role in the bilateral agreements with NASA and other partners through which data is collected, as well as EUMETSAT's limited own space-weather date gathering at present.
- **Modelling, warnings and alerts:** To assess attribution for the Met Office's role in providing space weather warnings, this study considered its role among other international organisations and service providers involved in space weather forecasting[29]. The lower bound was established by attributing an equal share to all, at present, fifteen international space weather services providers. As a central estimate the analysis only considered the five centres providing a 24/7 operational space weather service[30]. This assumes that in the absence of a Met Office, there would still be around-the-clock operational support provided by the other centres. As an upper-bound the study attributed 50% to the Met Office considering that the Met Office is one of only two centres providing space weather

[29] The list of organisations and current providers involved in space weather was obtained from the Partners and Stakeholders part of the NOAA's website: https://www.swpc.noaa.gov/about-space-weather/partners-and-stakeholders [accessed 02/02/2024]

[30] To the best of current knowledge this includes the Met Office in the UK, two centres in the US (NOAA's Space Weather Prediction Centre, and the US Air Force), and one centre each in South Africa and Japan and Finland.

alerts in the UK[31]. This assumption assumes that without the Met Office there would still be UK forecasts (though it should be noted that UK-based 24/7 operational support would no longer be available).

- **Operational support, advice and preparedness:** As a 24/7 staffed operational space weather centre, and the only such in the UK**,** the Met Office plays a key rule in providing operational support and advice. In addition, the Met Office actively works with a range of organisations in critical sectors such as energy, telecoms, rail, strategic roads, maritime, aviation, PNT, police and local resilience forums to help prepare these organisations for emergencies affecting their operations. This also includes work in the electricity sector such as operators of the high voltage grid and energy generators to help them understand what their vulnerabilities look like, to help with the decisions they might make in response to a severe weather event, and to help design the operational response processes put in place. Given this, this study's assessment is that Met Office's contribution to the operational support, advice and preparedness element should be assumed as relatively high. However, in the absence of quantitative evidence the analysis assumes a wide range - 30% to 70% - capturing the uncertainty. The midpoint of this range was used as the central assumption.

Combining the assumptions across these different contribution channels suggests a range of 12% to 44% for the Met Office's contribution with a central assumption of 24%. The central assumption was used in the calculation of the central estimates, while the whole range was used for the sensitivity analysis. The table below summarises the assumptions made.

Table 12 Attribution assumptions – space weather avoided damage

Component	Min	Central	Max
Data collection, sensors, satellites	0%	5%	13%
Modelling, warnings and alerts	7%	17%	50%
Operational support, advice and preparedness	30%	50%	70%
Assumed attribution	**12%**	**24%**	**44%**

Source: London Economics

The estimates in the literature relate to the impact of *severe space weather events* only, while estimates of the direct economic impact of *everyday* space weather could not be found. Moreover, Oughton et al. (2019) only considers impacts on the electricity transmission infrastructure. There are likely a wide range of other impacts in other sectors not valued. Hence, it is worth noting that the estimated benefit likely substantially underestimates the full impact.

In particular the following areas of likely impact of space weather events should be noted:

1) **Impacts on the electricity grid / electric power:** The estimates used in this study.
2) **Impact on satellites (e.g., debris avoidance):** Not quantified as there is no commercial market as of yet, so no benefit can be ascribed to the Met Office yet. However, this area is expected to become much more important in future.
3) **Impact on GNSS**: Recent estimates by London Economics (2023) suggest impacts of a loss of GNSS, e.g., because of a space weather event, could be substantial – at around £13.6bn

[31] The other UK centre providing space weather alerts ins the British Geological Survey (BGS). BGS issued alerts can be found on their website at: https://geomag.bgs.ac.uk/data_service/space_weather/alerts.html [accessed 02/02/2024]

per annum. While some impact could be ascribed to the Met Office, responsibility for mitigating space weather impacts on the GNSS infrastructure is assumed to lie predominantly with the space agencies (i.e., NASA/ESA/UKSA).

4) **Impact on Aviation:** Significant impacts on aviation are also likely. For example, the Canadian Space Agency estimates space weather impacts on polar aviation to be up to $1,750.0 M (CSA, 2019). However, these impacts are excluded to avoid double counting with the aviation benefit streams evaluated separately.

5) Impact **on global trade and UK supply chains:** An extreme space weather, such as that assumed in the 1-in-100-year scenario, was estimated by Schulte in den Bäumen (2014) to lead to substantial disruption of global supply chains with a daily cost of Daily cost of £20bn. While the Met Office would likely play some role in mitigation, there are many different actors involved and attribution would be very difficult to establish.

6) **Impacts on other sectors**: In addition, there are a wide range of other sectors that would likely be impacted, for example, marine transportation, magnetic surveying, etc.

Innovation activities - commercial catalytic benefits

As part of the Met Office's scientific and innovation-related activities, the Met Office undertakes a number of innovation activities seeking to develop new techniques and products. These products, if successful, deliver economic growth and in some cases develop nascent markets.

Following the approach set out in the 2015 General Review, a market-based approach was used in which the commercial catalytic benefits of Met Office innovations are estimated by the social return on sector profitability, which serves as a proxy for public science investment in the absence of more specific data, in key sectors.

Figure 26 Benefit stream for commercial catalytic benefits

The social return on public science investment is estimated to be between 20%-50% based on Haskel et al. (2014). For this analysis a 30% social return is assumed for the baseline estimate, with a higher bound estimate calculated using a 50% social return.

ECMWF benefits

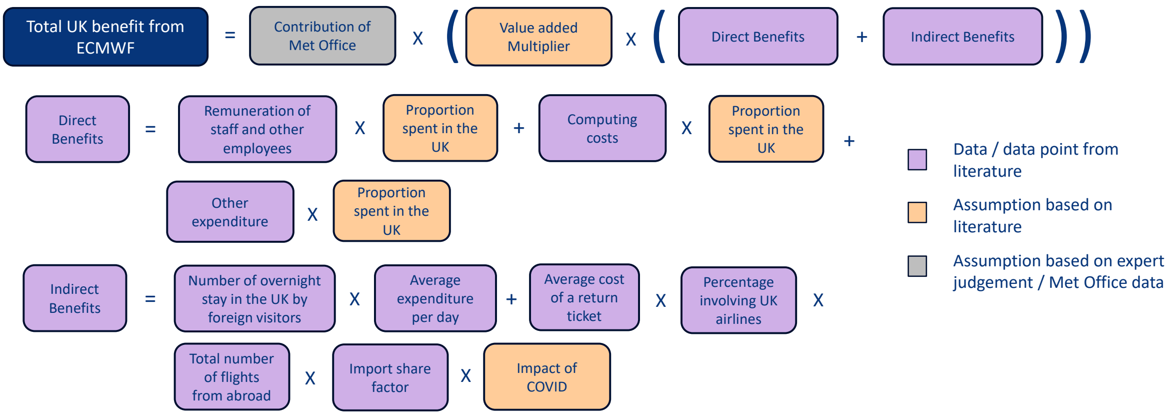
Benefits of international partnerships accruing outside the UK are beyond the scope of this study. Moreover, soft benefits such as increased international standing are difficult to quantify. As such, international leadership and partnership benefits were mostly evaluated qualitatively in the previous evaluation. This will also be the approach taken for this updated study. However, the previous evaluation did provide the following two value-streams which will be updated.

UK benefits from ECMWF

One way to narrowly estimate the benefits of the Met Office's international collaborations and partnerships for the UK economy is to look at the direct and indirect economic impact that a partnering organisation has on the UK and adjust it by the contribution of the Met Office to this organisation. For example, the headquarters of the ECMWF are located in the UK, which would not be the case if the Met Office did not have a close partnership with the ECMWF. There are various direct and indirect benefits from having the ECMWF HQ in the UK. Figure 27 lays out the evaluation framework to estimate these benefits, which was applied in the 2015 General Review.

The direct benefits refer to any direct expenses that the ECMWF makes in the UK. Indirect benefits are the expenses that foreign visitors to the ECMWF's UK headquarters incur. Adjusting these expenses by the proportion spent in the UK and the contribution the Met Office makes to the ECMWF yields the UK net benefit from the ECMWF. While the data in the calculation of the direct benefits can be drawn from the ECMWF annual report in 2022 (ECMWF, 2022), COVID-19 and the increased shift to home working may have altered the time that ECMWF staff spent in the UK. As such an additional assumption on the impact of COVID-19 on the reduction in travel by staff visiting the UK has been added, although for the baseline estimate this assumption is set to 100%. This does not capture the benefits the Met Office accrues from use of ECMWF data in producing its products and services.

Figure 27 Evaluation framework for estimating the UK benefits from ECMWF



Source: London Economics

Value of science partnerships

This benefit stream captures the value of science partnerships of the Met Office. The value is based on an internal estimate of the value of a range of science partnerships by the Met Office.

In the 2015 General Review, the value of these partnerships was placed at £15 million for 2014. This was based on a Met Office Science Advisory Committee (MOSAC) report from that time. The report provided an estimate of the research gearing from Met Office Science Partnerships. For the current study, the Met Office supplied an updated valuation of the estimates provided in the 2014 report:

> "Science Partnership continue to provide the Met Office with significant research gearing, estimated to have been worth over £28m for 2021/22. This is based on 123 projects where 115 (93%) of these could not have been achieved (or could not have been achieved as effectively or as quickly), without collaboration. Only 5 could have been achieved without external effort or knowledge and 25 could have been achieved but over a much longer timescale. The vast majority of the projects or work contribute a combination of underpinning scientific or technical development. This can be broken down as follows:
>
> - UM international partnerships £3.4m
> - UK Academia: £5.7m

- NERC JWCRP activities through shared direct programmes: £3.8m
- EU projects: £1.8m"

To account for future growth in the value of science partnerships, the growth rate from 2014 to 2022 was calculated and applied to each year going forward from 2022 to estimate the value of this payment across the 2024-2033 period.

A2.2 Met Office costs and revenues

The analysis presented in Section 4.1 (Table 5) evaluated benefits relative to two cost scenarios:

1) Total benefits including commercial contract and other revenue is compared to total Met Office costs.
2) Benefits to the UK economy (i.e., excluding contract and other Met Office revenue) are compared to the total public investment in the Met Office (i.e., the total cost to the UK exchequer).

Overleaf an overview of the calculations used to estimate the total costs, revenues and public investment is provided for the baseline 'Existing' Met Office scenario. Adjustments to costs under the 'Basic' Met Office scenario are discussed in Annex A2.5

Table 13 Calculation of baseline Met Office costs, revenues and public investments

Costs	£-value	Comment
Total OPEX	£3.08bn	
+ Total CAPEX (excl. supercomputer)	£0.39bn	
Total costs	**£3.47bn**	
- Defence costs	£0.62bn	Excluded as out of study scope
Total costs excl. defence	**£2.86bn**	
+ Total supercomputing costs	£1.17bn	
Total relevant Met Office costs	**£4.03bn**	
Present value of total costs (@ HMT 3.5% discount rate)	**£3.47bn**	**Costs used in calculation of total Met Office benefit-to-cost ratio (Table 5)**

Revenues	£-value	Comment
PWS funding	£1.72bn	
+ Other public funding	£0.44bn	
+ Defence funding	£0.33bn	
+ Commercial contract revenue	£0.36bn	
+ Other revenue	£0.29bn	
Total Met Office revenue	**£3.15bn**	
- Defence funding	£0.33bn	Excluded as out of study scope
+ Supercomputer funding	£1.17bn	
Total relevant revenue	**£3.99bn**	
Present value of total revenue (@ HMT 3.5% discount rate)	**£3.43bn**	**Revenue used in calculation of total Met Office benefit-to-cost ratio (Table 5)**

Public investment	£-value	Comment
Total public funding (excl. defence)	£2.07bn	
+ Supercomputer funding	£1.17bn	
Total relevant public investment	**£3.25bn**	

Present value of total public investment (@ HMT 3.5% discount rate)	**£2.80bn**	**Public funding against which benefits are assessed for return on public investments (Table 1)**

Note: The table provides the calculation steps for total Met Office costs and public investments in the Met Office used in the 'Existing' Met Office base-case.

Source: London Economics analysis of Met Office costs/revenue data

A2.3 Inputs, quality and benefits method

The overall quality of the services provided by the Met Office and the level of benefits achieved depend on a variety of factors. This of course includes properties of the forecasts themselves, for example:

- **Accuracy** – the percentage of forecasts which are "correct"
- **Frequency** – the time-step between forecasts (hourly / daily / weekly etc)
- **Timeliness** – the lag (warning time) between forecast and event
- **Resolution** – the geographical granularity of a forecast

However, the level of benefits achieved also depend on factors not directly related to the quality of the forecasts. This includes the reach of the forecasts (i.e., who sees the forecasts) and behavioural factors. That is, what do users do with the forecasts, how useful is the information to them, and whether and how effectively they response to the information:

- **Awareness** – weather forecasts are seen by the relevant actors (e.g.,
- **Usefulness** – whether the information is understood by its users and enables informed decision-making
- **Response** – whether users take action in response to the information
- **Effectiveness** – the effectiveness of actions taken by consumers of the information

A2.4 Treatment of future improvements in quality

Given the high importance of forecasting accuracy for the Met Office's internal performance evaluations, and the difficulty of measuring the other factors, the previous evaluation assumed changes in outputs / benefits to be linear to changes in quality. Assuming changes in inputs are above the minimum thresholds required, the Stone-Geary production function used in this study can be shown to yield a similar linear relationship (see Section A1.1.3).

Previously the main measure the Met Office used to measure the accuracy of its global numerical weather prediction was the Global NWP Index, which measured the performance of the Met Office's Global Deterministic Model. The index verified the accuracy of a basket of Met Office forecasts such as surface temperature, wind speed, surface visibility, cloud cover, and precipitation. The higher the Index, the more accurate the forecasts.

Due to the difficulty in measuring non-quality elements over time for all benefit streams, changes in quality were, in the previous study, proxied by the NWP index. That is, the NWP index was used as a proxy for 'quality' and link between expected future changes in quality (as measured by changes in the NWP index) to future changes in benefits.

The current study follows the approach. However, given the Met Office's strategic decision to move to fully ensemble-based forecasts, the Global NWP Index was discontinued in 2023 and a "Global Ensemble skill" metric has been introduced.

However, to account for annual fluctuations in quality-improvements, this study, in line with the previous 2015 General Review, takes an average of quality improvements over a number of years (specifically the previous ten years). Due to the newness of the Global Ensemble skill metric, the NWP index was used as the basis to proxy historic changes in quality. In future this metric should be replaced by changes in the Global Ensemble skill metric.

As in the previous study, evidence on benefits growing faster/slower than expected changes in quality is taken into account. The specific relationships assumed for all benefit streams is discussed in Table 14. The study allowed for a 50% uncertainty range around the central assumptions in the sensitivity analysis (see discussion in Box 6).

Table 14 Relationship between quality and benefits

Benefit stream	Assumed relationship
Flood and storm damage avoided	The study assumes decreasing returns to quality in line with the Day's Curve, which places a limit on the flood damages that can be avoided through better warnings (even with the most accurate and timely forecasts properties cannot be moved and so some damage is unavoidable). The Day's Curve is strictly designed for flooding only. However, in line with the previous evaluation the Day's Curve is applied to storm damage on the assumption that this delivers a better approximation of the relationship than a linear model. This is because both flooding and storm damage impact on fixed and mobile household and business assets in a sufficiently similar manner.
Aviation	The study uses an accuracy metric for wind at flight levels (~250hPa) instead of the general basket of metrics in the NWP/Global Ensemble skill metrics. Changes in benefits are assumed to be in line with changes in accuracy of wind forecasts at flight levels. Specifically, the study assumed an average annual growth rate of 1.4%, which is in line with the average growth in the selected wind metric over the last decade.
Climate adaptation benefits	Climate adaptation benefit estimates already estimate the level of benefits for future years as part of their estimations. Therefore, no further quality adjustments to future benefits are made.
Government dividends, science partnerships, ECMWF expenditure in the UK	The study assumes there is no relationship between the level of dividends, value of science partnerships, and ECMWF spend in the UK and quality. Benefits are assumed to remain constant in real terms.
Other benefit streams	A linear relationship between quality, as measured by the NWP/Global Ensemble skill, and the level of benefits is assumed for all other benefit streams. Benefits are assumed to grow in line with improvements in quality. Specifically, the study assumed an average annual growth rate of 0.9%, which is in line with the average historic growth in the NWP index over the last decade.

Source: London Economics

Nevertheless, while overall growth in benefits remains solely linked to growth in quality, reach and behavioural elements are considered in some benefit streams. In particular:

- The valuation approach for industry benefits was aligned with Ross (2019a) which directly takes into account overall reach and response factors (see Annex A2.1.1).
- Monetisation of benefits of weather provision to the public is based on a Willingness-to-Pay (WtP) survey of the British public which considered both aspects of quality as well as non-quality factors such as availability, ease of use, etc.

Evidence of changes in reach and behavioural factors for these benefit streams can therefore be captured through changes in input assumptions (for industry and climate benefits) or administering an updated WtP survey in the future (for public benefits). Other benefit streams could in principle be aligned to this framework, though this would require additional work beyond the scope of this study. For example, the flood and storm damage valuations use an assumption on the proportion of flood/storm damage avoided due to warnings. This assumption of course is in turn influenced by awareness among responders and the general public, their understanding of the warnings, and the effectiveness of the actions they take in response.

A2.5 Further details on the 'Basic' Met Office scenario

A basic service is assumed to continue to provide weather information and forecasts to the public, though these would be of a lower quality. The Met Office would also continue to exchange meteorological information and observational data with international partners and fulfil its regulatory-mandated responsibilities to the aviation sector. Other services such as the Met Office's climate services, and specialist services such space weather forecasts, would not be provided.

Crucially, a more basic service would also lose many of the soft-power benefits associated with a world-leading meteorological service. Many of these benefits could not be quantified, and so are not quantitatively reflected in the modelling of the basic service. Nevertheless, the modelling assumed that related benefits of having the ECMWF headquarter in the UK and the limited international leadership benefits that could be monetised do not materialise. The Met Office's position as a World-Area-Forecast-Centre would also no longer be tenable.

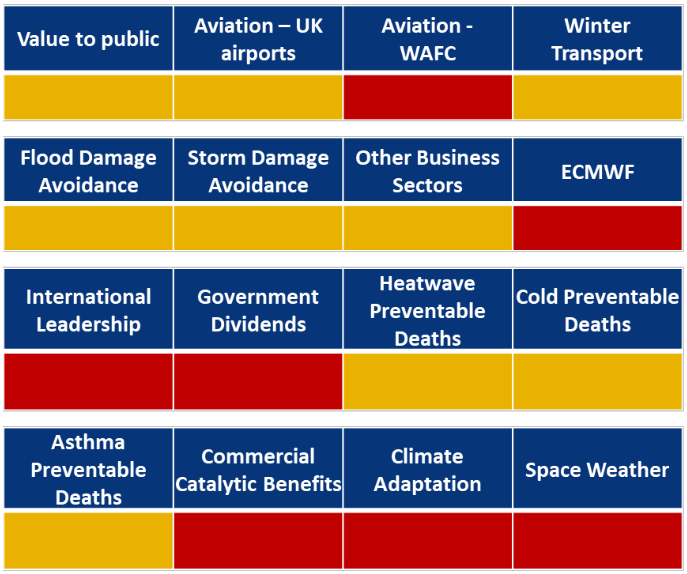
In addition, the Met Office would also no longer be able to provide its critical defence services with significant knock-on effects to a range of critical national services (out of scope and therefore not explore further in this study).

Box 3 in Section 3.2 already lists the services provided and so these are not repeated here. Instead, this section focuses on the modelling assumptions used in the analysis of the 'Basic' Met Office.

A2.5.1 Modelled benefits under the 'Basic' Met Office counterfactual scenario

To estimate the benefits under this scenario that would still be provided but at a lower quality, the analysis applied a one-third (33.3%) quality reduction to the benefit calculation. This was judged, in discussions with the Met Office, to be reasonable. However, the precise quality reduction is difficult to judge without further work. Therefore, in the sensitivity analysis, we allow for quality reductions of between 20% to 40%. Figure 28 details which benefit streams are assumed to be no longer provided (red) or provided at a reduced quality (amber) under the counterfactual scenario, whereby the Met Office provides 'basic' meteorological services.

Figure 28 'Basic' Met Office counterfactual - benefits affected / no longer provided



Note: **Orange:** Service still provided but there is a reduction in quality. **Red:** Service no longer provided.

Source: London Economics

In addition, the analysis assumed lower future quality growth trajectories (and thereby reduced growth in benefits) than under the baseline scenario. Reduced growth in quality was assumed to reflect reduced investments in supercomputing and the reduction in expert staff under this scenario. Concretely, the central estimates assume that there would be no additional growth in quality, while the upper bound assumes similar growth to the central growth assumptions in the baseline scenario.

A2.5.2 Costs under the 'Basic' Met Office counterfactual scenario

Under the counterfactual scenario, where the Met Office only provides basic meteorological services, the study assumes that there is a reduction in costs. It is difficult to make precise assumptions on what costs in this hypothetical alternative scenario would look like. However, to make a sensible approximation have assumed the following reductions:

- **Observations – small reduction (assumed 5%):** The study assumes most observational data would still be required to provide the basic weather and climate services, although there may be a small reduction due to fewer services and less granularity. The study therefore assumed a minimal reduction in observation costs only. Internal analysis by the Met Office suggested this small reduction would be in the region of 5%.
- **Supercomputer – large reduction (assumed 60%)**: The study assumes that under a basic service, the new supercomputing capabilities would not have been required. Instead, a more basic upgrade/cycle similar to previous investments could have been maintained. Comparing total supercomputing investments from the previous General Review to the new supercomputing costs would indicate a ~60% increase in real-term expected supercomputing spend. The study therefore assumed a hypothetical 60% lower supercomputing investment under the counterfactual. However, in reality the transition back to a smaller supercomputer would be difficult as the increase in capabilities is already predetermined and so costs would still incur (see below).
- **Expert staff – medium reduction (assumed 40%):** Under a basic service there would be fewer expert meteorological and science staff needed. In line with the Met Office's own internal assumptions, the modelling assumes a 40% reduction in headcount under the

assumed basic service. Again, such a transition would be difficult in reality and incur substantial transitioning (e.g., redundancy) costs.

- **Other OPEX/CAPEX costs – small reduction (assumed 5%):** It is expected that the main reduction in costs associated with providing a basic service would be expert staff costs and supercomputing costs. It is expected that other operational/capital expenditure such as equipment, maintenance, etc. would still be incurred, though the modelling assumed there may be a small reduction in costs over the ten year period. In the absence of credible data for the likely magnitude of this reduction, the reduction was assumed to be in line with the reduction for observations.

It should be noted that the analysis considers a hypothetical scenario in which the Met Office would operate as a 'Basic' service. It therefore considers the services a 'Basic' Met Office would provide alongside the staff, computing and other input requirements such as service would have. However, the modelling does not analysis the transition from the existing Met Office to a more basic service.

Were such a transition to actually take place, this would be highly complex, would likely take several years, and incur substantial additional costs which are not modelled. These include redundancy costs, transaction costs for moving to smaller premises. Crucially, the supercomputing funding contracts are already predetermind. As such while a more basic service would not need the increased supercomputing capabilities, the costs would still be incurred and the realised benefit to costs ratio would be substantially lower in the transition period.

With respect to revenue, all commercial contract revenue was removed (assuming the Met Office would not provide advisory/consultancy services under a basic met offering), whilst public funding (excl. defence) was assumed to cover the full costs to provide this basic met service.

Resulting total present costs under this scenario are there **£2.3bn**. Public investment is assumed to be the same as costs in this scenario, as there is no commercial revenue in this scenario.

A2.5.3 Additionality: Would Met Office activities and services be delivered anyway?

Another factor to consider is whether in a do-nothing or do-minimum world the activities and services currently provided by the Met Office would be provided by an alternative organisation such as the private sector or meteorological services from other countries. In economic terms this concept is known as **additionality** and refers to the benefits that would have occurred anyway.

While both the private sector and other meteorological services currently provide meteorological information for the UK it is unlikely that these organisations would replicate the service provision of the Met Office in either scenario (though they may provide some basic meteorological offerings).

Both private sector organisations and other meteorological services rely on the Met Office's extensive underlying capabilities. This includes extensive physical infrastructure such as its observations network and investment in EUMETSAT satellites Without these capabilities the service other organisations are able to provide would be severely limited. While other organisations could invest in these capabilities, they are very expensive and the private weather market across the world looks to governments to provide these underlying investments.

Similarly, the Met Office's scientific research and activities has powered many of the meteorological modelling improvements in the past. Such science and research activities are high-risk and therefore unlikely to be undertaken by the private sector. The Met Office provides soft power and network benefits from which other organisations benefits. For example, UK access to other meteorological services' observations is provided on an exchange basis whereby other organiastions benefit from access to the Met Office's own observations. These relationships would be difficult to replicate for private sector organisations.

Finally, while private sector or other organisations may provide some meterological services, other key services provided by the Met Office do not have a commercial revenue potential for private sector organisations and so would be unlikely to be provided. This includes, for example, the Met Office's severe weather warnings and its work with the civil contingency community. While the UK government could pay private sector organisations to provide this service, this would not change the public returns on these investments unless private sector organisations could deliver these services at a substantially lower cost. However, this is unlikely to be the case in many of the services the Met Office provides due to regulatory and/or resilience requirements as well as the large capability investments needed to enable these services.

A2.6 Other methodological considerations

A2.6.1 Inflation and discounting

All costs and benefits are presented in 2024 real discounted prices. To discount future benefits, the study used the HM Treasury Green Book discount rate of 3.5%. Monetary values relating to previous years (e.g., literature estimates) were converted to 2024 prices using GDP deflators from the ONS/OBR. Future inflation assumptions were made in line with the March 2023 OBR forecast (the latest available at the time of modelling). In line with Green Book guidance, the analysis used the last year for which the OBR provided a growth forecast for future years outside the OBR's forecast range.

A2.6.2 Avoidance of double counting

Due to the holistic nature of the Met Office's service provision, there are activities which the Met Office undertakes that will incur benefits across multiple areas. Wherever possible this study has minimised the amount of impact which could be considered as 'double counting', i.e. the benefits from one activity are counted in more than one stream estimate.

For example, consultancy activities are not quantified separately in this analysis as the overall benefits to sectors benefitting from consultancy and advisory activities are already estimated in a different way. In addition to consultancy activities, estimates for the following sectors were adjusted to avoid double counting benefits:

- **Other business sectors:** To avoid double counting with the other industry benefit streams, the study only evaluates these benefits for sectors for which benefits were not directly estimated. These include the finance, insurance and real estate sectors (to avoid overlap with extreme weather warnings), transportation and storage (to avoid overlap with winter transport and aviation benefits), and public administration and defence (as defence is out of scope and public sector benefits are captured in other streams).
- **Weather and climate science:** As many of the outputs of the Met Office's science and research activities support and enable the delivery of other Met Office services, parts of these benefits are already accounted for in the evaluation of the other benefit streams. For example, the climate adaptation benefits estimated in the climate services sector already cover an important part of the benefits that arise from the Met Office's climate science activities. If the economic impact of the scientific output of the Met Office was estimated again, the benefits would be double counted. Therefore, as in the last

evaluation, the value of weather- and climate science activities themselves were not monetised. However, as in the previous study, an assumption will be made on the contribution of scientist, modellers, and forecasters to the overall Met Office benefits.

- **Land transport**: The land transport sector benefits focuses on the impact during winter, from the associated inclement weather. Benefits to this sector are not considered in the other months of the year to avoid double counting benefits with the other business sectors stream.
- **Benefits from science, innovation and technology**: Science, innovation and technology activities are key enabling activities for all benefit streams valued in this study. Therefore, with the exception of a very narrow set of innovation activities, benefits associated with these activities were not valued separately. In particular, benefits not valued separately include social and economic benefits that may be accrued from academic research conducted by the Met Office as well as benefits from dataset provision itself.

A2.6.3 Commercial vs. non-commercial

As a trading-fund part of the Met Office's revenue, and therefore resulting impacts, derive from commercially funded work such as the Met Office's consultancy activities. It is difficult to fully disentangle the share of benefits attributable to public vs. commercial funding, partly because commercial revenue in turn supports the Met Office's general activities. Nevertheless, the table overleaf distinguished, in so far as possible, whether monetised impacts relate to publicly funded and/or commercially funded work of the Met Office.

Table 15 Attribution of impacts to commercial and non-commercial funding

Benefit stream	Public funding	Commercial funding	Assessment
Weather services			
Value to the public	✓		This benefit stream relates to public weather information provision which falls under PWS.
Flood damage avoidance	✓		Severe weather and standard forecasts provided as part of the PWS.
Storm damage avoidance	✓		
Preventable deaths from heat	✓		Extreme temperature warnings and specialist forecasts are provided under the PWS.
Preventable deaths from cold	✓		
Preventable respiratory illness deaths	✓		
Climate services			
Climate adaptation benefits	✓	✓	Climate research is publicly funded. However, the Met Office also provides climate consultancy services to industry. While these ideally would be disentangled from wider climate adaptation benefits (and counted under benefits to industry) the use of literature estimates on the benefits of better climate adaptation does not make this possible. This is because estimates of improved adaptation include, to some degree, improved adaptation by industry.
Benefits to industry			
Value to the aviation sector	✓	✓	Aviation services are partially funded by commercial revenue from the aviation sector. However, forecast information used in aviation is from the PWS.

Benefit stream	Public funding	Commercial funding	Assessment
Value to (winter) land transport	✓		The value stream predominantly captures benefits to road users as a result of provision of weather information. Whilst there are consultancy activities in the land transport sector, they are not considered in the benefit estimation.
Value to other business sectors	✓	✓	Other business sector benefits capture impacts from provision of weather and climate information through PWS. However, part of the value is also derived through the Met Office's commercial weather and climate consultancy activities.
Other monetised benefits			
Benefits from international partnerships	✓		The Met Office's contribution to the ECMWF and other key international partnerships are paid through the PWS.
Government dividend	✓	✓	The government dividend is a result of Met Office profits as a trading fund. Therefore, part of it is a result of the Met Office's commercial activities.
Catalytic commercial benefits	✓		This benefit stream captures the social return on public science investments in key sectors.
Space weather benefits	✓		Space weather advice, forecasts and warnings are provided by the Met Office through public funding. While the Met Office have a few contracts with organisations such as ESA, there are at the present time no truly commercial contracts and there currently is no commercial market for space weather data/services.

Source: London Economics

A2.6.4 Impacts of COVID-19

It is possible that lingering effects of the Coronavirus pandemic have an impact on the level and/or future trajectory of benefits. While exploring the potential impacts of COVID-19 in detail was beyond the scope of this study, it is nevertheless important to acknowledge them.

Societal shifts stemming from the pandemic could impact benefits in a variety of ways, for example:

Table 16 Potential impacts of COVID-19 on estimated benefits

Benefit stream(s)	Magnitude & impact on estimated benefits
Aviation & ECMWF	COVID-19 caused severe disruption and economic impacts to the aviation sector. Lingering changes to travel patterns could impact the level of benefits as assumptions are based largely on pre-pandemic evidence. For aviation, ongoing shifts in travel patterns would impact flight volumes and therefore estimated aviation benefits. For ECMWF benefits, the shift to flexible and hybrid working could mean less business travel to the UK and therefore lower indirect benefits, i.e., lower expenditure in the UK by foreign visitors to the ECMWF headquarters. The magnitude of aviation benefits as a share of total estimated benefits mean ongoing impacts in this sector could have a large impact on benefits. While COVID-19 had substantial short-term impacts on the aviation sector, the impacts over the studied period (2024-2033) are expected to be small. Findings of a DfT (2021) study exploring the impacts of COVID-19 on business travel (the population relevant for ECMWF benefits) suggested that by end of 2022, the proportion of businesses conducting domestic travel would have returned to pre-pandemic levels. This is reflected in flight data with recent OAG (n.d.) data showing that 2023's yearly capacity total was just 3.7% below 2019, suggesting travel volumes have now broadly returned to pre-pandemic levels. Therefore, central estimates assumed no ongoing impacts of COVID-19 on these benefit streams. Nevertheless, potential impacts are accounted for in the sensitivity analysis. For aviation, this is implicitly captured by allowing for uncertainty around each input assumption. For indirect ECMWF

Benefit stream(s)	Magnitude & impact on estimated benefits
	benefits, an explicit assumption was added to allow for lower UK expenditure in the sensitivity analysis.
Value to the Public	The assumptions used to estimate the value to the public were informed by a separate willingness-to-pay survey of the public undertaken alongside this study. While that study did not explicitly consider impacts of COVID-19, it was undertaken following the pandemic and as such ongoing impacts of COVID-19 would have implicitly accounted for in the public's responses. Nevertheless, sensitivity analysis around the central value and the future trajectory of the valuation allows for a degree of uncertainty.
Other Business Sectors & Winter Transport	As with aviation, COVID-19 has caused substantial disruption to the economy. However, ongoing shifts in the way people work (e.g., hybrid working) mean there are likely to be continued impacts over the study period (2024-2033). However, the impacts of changes are complex and difficult to model and will differ substantially across sectors of the economy. For example, for the events sector the increased use of virtual conferencing solutions may mean that the sector is less impacted by weather events – with events being able to operate hybrid or move to fully remote in case of disruption. On the other hand, some sectors may experience positive impacts, for example, the tourism sector may benefit from more flexible working options. At the same time many sectors are also unable to undertake their work remotely (e.g., construction workers, mining, etc.) and so there would be no impact. The main assumption modelling these impacts is the weather sensitivity of different sectors of the economy. Further research would be needed to make robust assumptions on the impact of COVID-19 on weather sensitivity of each sector. Further, these are now quite old, they are based on a study by Lazo et al (2011) and so could benefit from additional primary research to update them in any case. Behavioural factors such as the share of users aware of forecasts and the effectiveness of the response may also be affected. Similarly to other business sectors, there are likely going to be ongoing impacts of COVID-19 affecting winter transport. For example, the ability to work from home may mean a higher percentage of the UK public is able to avoid travelling in bad winter weather. Again, the assumptions underlying winter transport are now somewhat outdated and could benefit from new primary research. While the modelling does not directly account for the impact of COVID-19 on these assumptions, sensitivity around all assumptions is explored via the sensitivity analysis. The sensitivity analysis allows for both larger as well as smaller values of all assumptions. It also allows for some degree of variation in the future trajectory of benefits (see Box 6).
Flood / Storm Damage Avoidance	The impact of COVID-19 on flood and storm damages avoided is not clear. On the one hand, increased flexibility may mean more people can avoid travelling during severe conditions, thereby meaning damages are lower. On the other hand, properties and infrastructure cannot be moved and so a large share of damages would be unaffected. Assumptions underlying flood/storm damages are again quite old now and could benefit from primary research to update them. However, due to the incorporation of recent literature evidence the modelled damages are relatively conservative but allow for a wide uncertainty around damages (see Box 26). This means any impacts of COVID-19 would likely be captured by this wide uncertainty range.
Cold, Heatwave and Asthma Preventable deaths	Similarly to flood and storm benefits, the impact of COVID-19 is unclear without further research. Increased flexibility again may mean additional mitigation (e.g., by enabling more people to avoid leaving the house when pollen levels are high). However, overall the impact is likely to be small and captured by existing uncertainty ranges around assumptions made.
Climate adaptation	The implementation of lockdowns and restrictions of travel caused a temporary reduction in global greenhouse gas emissions and local air pollution (see Met Office n.d. d). At the same time, the substantial expenditure during the pandemic and resulting higher levels of Government debts around the world may impact climate ambitions going forward. Given the long time-horizon of climate impacts, it is too early to robustly understand the long-term impact of COVID-19 on climate adaptation benefits. However, as discussed in Annex A2.1.3, there is already a substantial level of uncertainty around climate benefits. Therefore, the modelled uncertainty range is already very wide and estimated central benefits are comparatively conservative. Any additional uncertainty would therefore likely have only a small impact.

Benefit stream(s)	Magnitude & impact on estimated benefits
Other	Other benefit streams (space weather, government dividends, commercial catalytic benefits) are not obviously affected by COVID-19. Therefore, any impacts would likely be negligible and/or captured by existing uncertainty ranges.

Source: London Economics

Annex 3 Full sensitivity analysis results

A3.1.1 Sensitivity analysis results for aggregate benefits

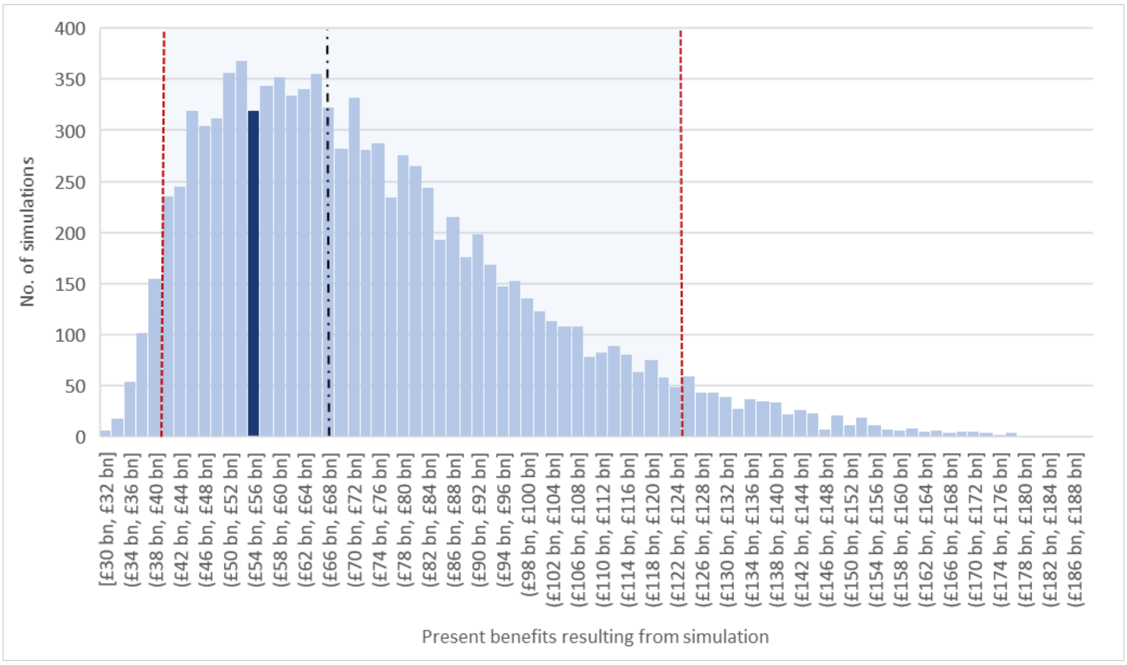
The figures overleaf provide the resulting uncertainty distributions around the central estimates for both the baseline and the 'Basic' Met Office counterfactual scenario. The analysis took the form of a Monte-Carlo simulation around the total estimated present benefits to the UK, over the next decade, associated with the Met Office's activities. The results are based on 10,000 simulations.

The central results presented earlier are indicated by the dark blue shaded bars. The black-dashed lines show the median[32] estimate of total present benefits from the simulations. The light blue shaded areas between the red-dashed lines represent the 90% confidence intervals.

The implied distributions for weather-related benefits only (i.e., excluding ECMWF, international leadership, catalytic benefits, commercial revenue, and government dividends) and the implied climate distributions[33] are also provided for reference. Please note, climate services are excluded under a 'Basic' Met Office and so no distribution is provided.

[32] The median is typically used instead of the mean as it is less skewed by outliers. Examining the median alongside the uncertainty range can be helpful to understand the shape of the distribution. If the median is in the middle of the range this suggests the implied distribution is more symmetrical. Conversely, if the median is closer to one end of the range, this indicates a skewed distribution, implying there could be significant outliers or a potential for large values on one side with a relatively lower probability.
[33] The underlying assumptions for climate benefits are discussed in the methodological annex for climate benefits - Annex A2.1.2.

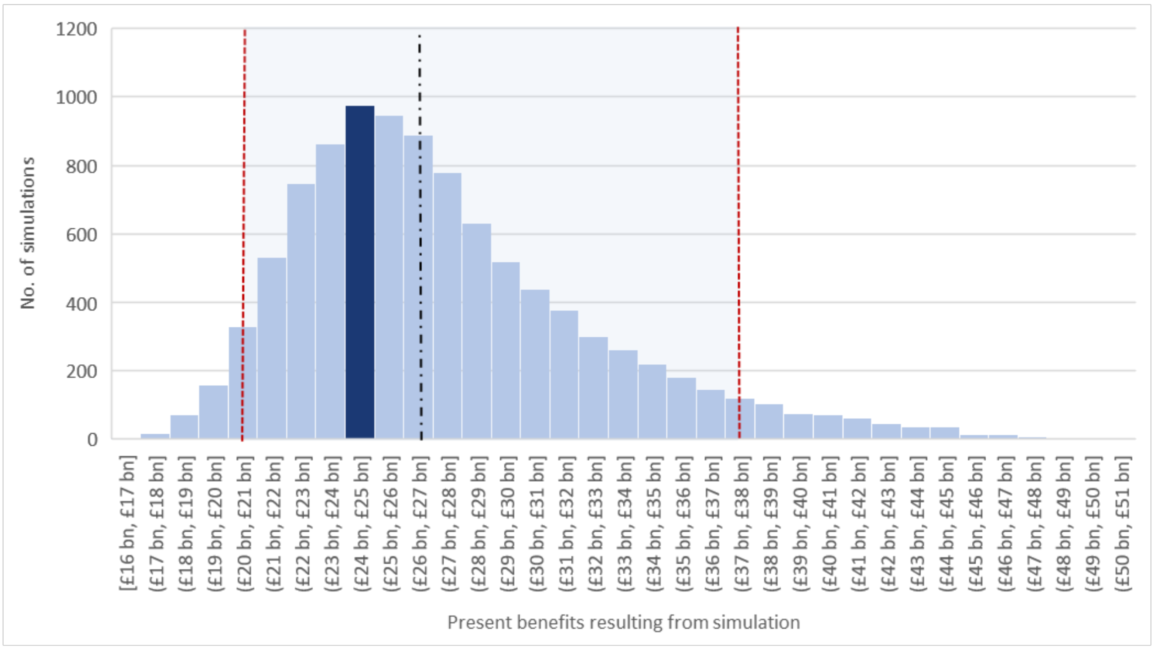
Figure 29 Sensitivity analysis results - estimated total present benefits ('Existing' Met Office)



Note: The graph shows the results of Monte-Carlo simulations around central assumptions for the estimation of total present benefits to the UK, over the next decade, associated with the Met Office's activities. The graph is based on 10,000 simulations. The central results presented earlier would fall within the dark blue shaded bar. The black-dashed line shows the median estimate of total present benefits from the simulations. The light blue shaded area between the two red-dashed lines represents the 90% confidence interval.

Source: London Economics

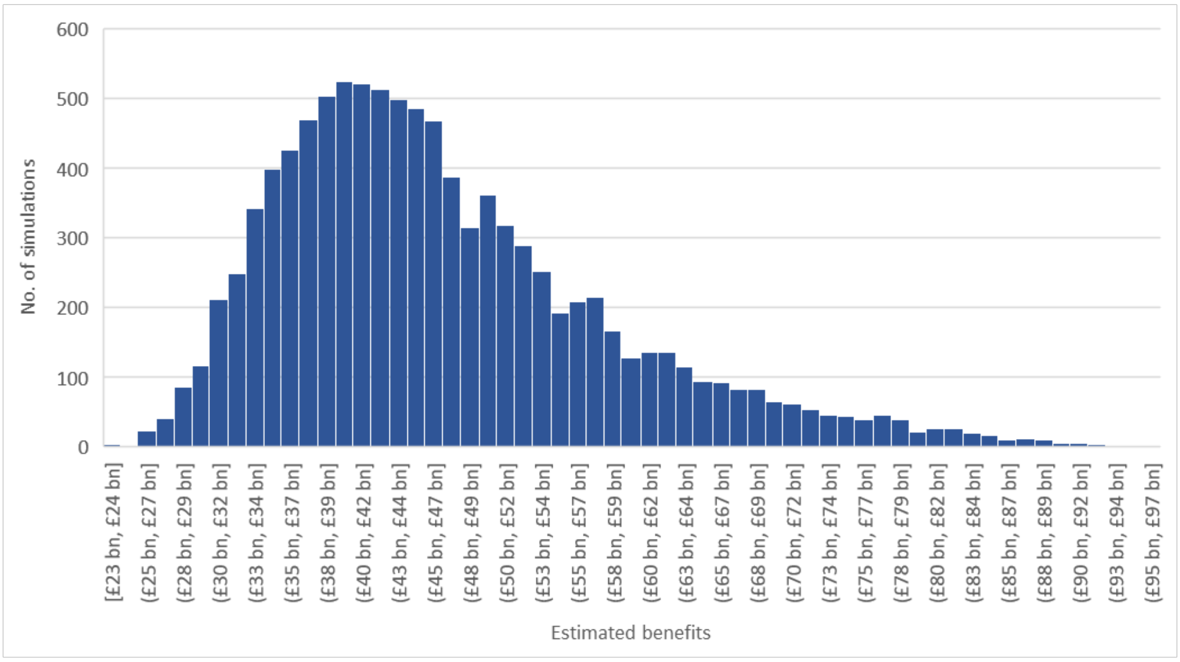
Figure 30 Sensitivity analysis results - estimated total present benefits ('Basic' Met Office)



Note: The graph shows the results of Monte-Carlo simulations around central assumptions for the estimation of total present benefits to the UK, over the next decade, associated with the Met Office's activities. The graph is based on 10,000 simulations. The central results presented earlier would fall within the dark blue shaded bar. The black-dashed line shows the median estimate of total present benefits from the simulations. The light blue shaded area between the two red-dashed lines represents the 90% confidence interval.

Source: London Economics

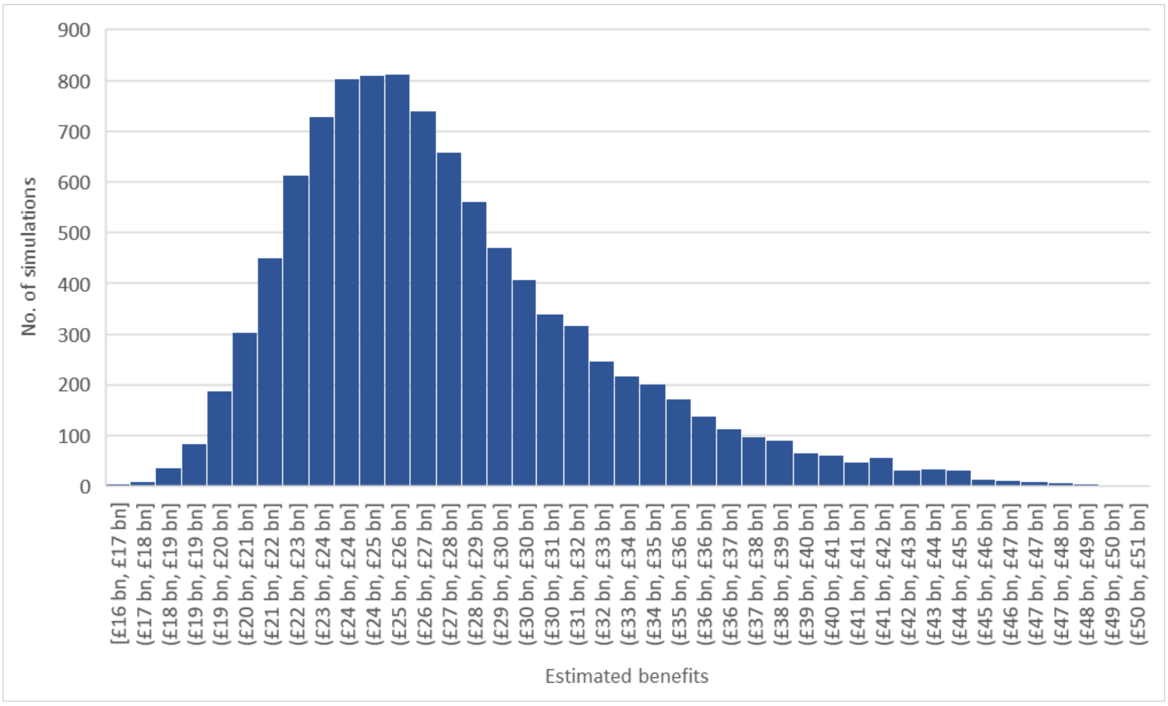
Figure 31 Sensitivity analysis results - estimated weather benefits ('Existing' Met Office)



Note: The graph shows the results of Monte-Carlo simulations around central assumptions for the estimation of total present benefits to the UK, over the next decade, associated with the Met Office's weather-related activities. The graph is based on 10,000 simulations.

Source: London Economics

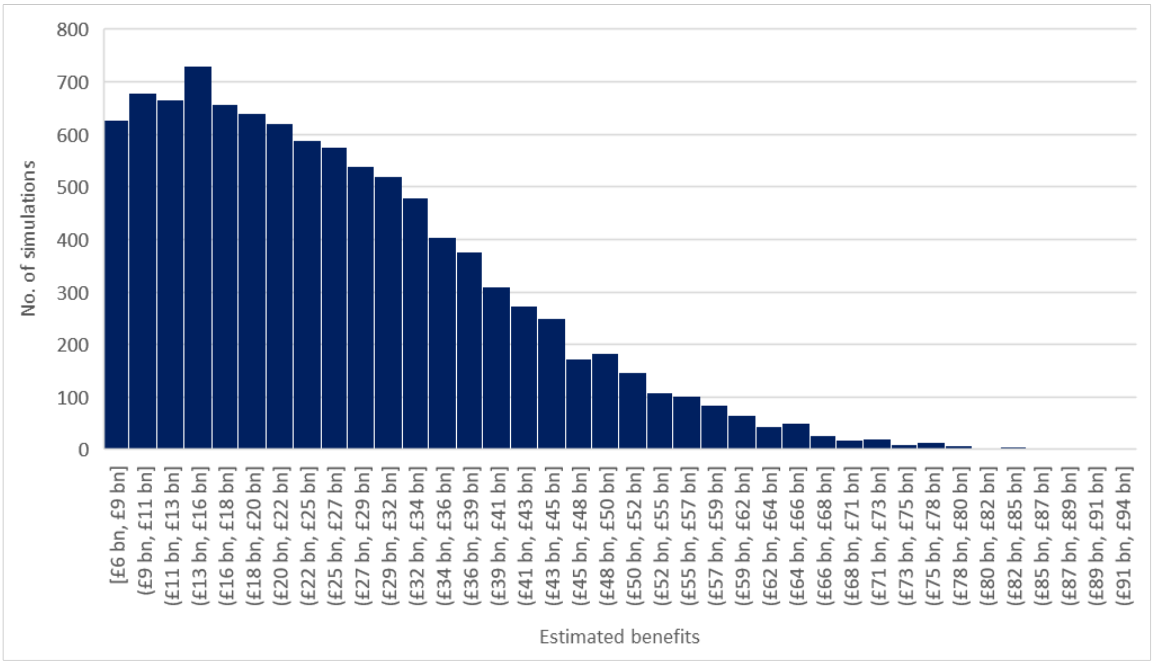
Figure 32 Sensitivity analysis results - estimated weather benefits ('Basic' Met Office)



Note: The graph shows the results of Monte-Carlo simulations around central assumptions for the estimation of total present benefits to the UK, over the next decade, associated with the Met Office's weather-related activities. The graph is based on 10,000 simulations.

Source: London Economics

Figure 33 Sensitivity analysis results - implied climate benefits ('Existing' Met Office)



Note: The graph shows the results of Monte-Carlo simulations around central assumptions for the estimation of total present benefits to the UK, over the next decade, associated with the Met Office's climate activities. The graph is based on 10,000 simulations.

Source: London Economics

A3.1.2 Sensitivity analysis results for individual benefit streams

Examining the detailed sensitivity results for each benefit stream would be very space intensive. Therefore, this section provides a summary of the results, specifically:

- Table 17 provides a summary of the results of the sensitivity analysis for each monetised benefit stream, under the 'Existing' Met Office baseline scenario. These results allow for both uncertainties around the assumptions made in modelling of each benefit stream itself, as well as uncertainty around future changes in quality and resulting benefits.
- Table 18 provides a summary of the results of the sensitivity analysis for each monetised benefit stream, under the 'Basic' Met Office counterfactual scenario.
- Figure 34 further provides the boxplots of the results of the simulation analysis for the 'Existing' Met Office base case. Boxplots are a way to visualise the uncertainty implied by the simulation results. They show the range of benefits most simulations resulted in (the central) box, the median ('X'), and any outliers representing large, estimated benefits occurring only in a small number of simulations (dots).

In addition to the summary results, Box 26 discusses the simulation results for flood and storm damages in further detail.

Table 17 Sensitivity analysis results - by benefit stream - 'Existing' Met Office base case

Benefit stream	Central estimate	Sensitivity analysis results		
		Median	Lower 90%	Upper 90%
Aviation	£12.5bn	£12.4bn	£9.7bn	£16.4bn

Climate Adaptation and Mitigation	£12.0bn	£23.9bn	£8.3bn	£53.7bn
Value to the Public	£11.6bn	£11.7bn	£7.6bn	£15.9bn
Other Business Sectors	£10.9bn	£10.9bn	£6.3bn	£17.3bn
Met Office Revenue*	£3.4bn	£3.4bn	£3.4bn	£3.4bn
Cold Preventable Deaths	£1.9bn	£1.8bn	£0.1bn	£11.9bn
Winter Transport	£1.5bn	£1.5bn	£0.6bn	£3.0bn
Flood/Storm Damage Avoidance	£0.8bn	£1.3bn	£0.2bn	£5.4bn
Space Weather	£0.6bn	£0.8bn	£0.4bn	£1.4bn
International Leadership	£0.4bn	£0.4bn	£0.4bn	£0.4bn
ECMWF	£0.3bn	£0.3bn	£0.1bn	£0.6bn
Heatwave Preventable Deaths	£0.1bn	£0.1bn	<£0.1bn	£0.8bn
Government Dividends	£0.1bn	£0.1bn	£0.1bn	£0.1bn
Asthma Preventable Deaths	<£0.1bn	<£0.1bn	<£0.1bn	£0.1bn
Commercial Catalytic Benefits	<£0.1bn	<£0.1bn	<£0.1bn	<£0.1bn
Total present benefits	**£56.0bn**	**£68.8bn**	**£41.4bn**	**£124.8bn**

Note: The graph shows the results of Monte-Carlo simulations, for each monetised benefit stream, around the total estimated present benefits to the UK, over the next decade, associated with the Met Office's activities. The graph is based on 10,000 simulations. (*) Revenues are excluded in the estimates of the return on public investment as i) commercial contract revenues are a transfer payment from UK businesses to the Met Office and so have a net-zero benefit to the UK taxpayer, and ii) non-commercial Met Office revenue is predominantly public funded and so while it is a benefit to the Met Office it is a cost to the UK taxpayer.

Source: London Economics

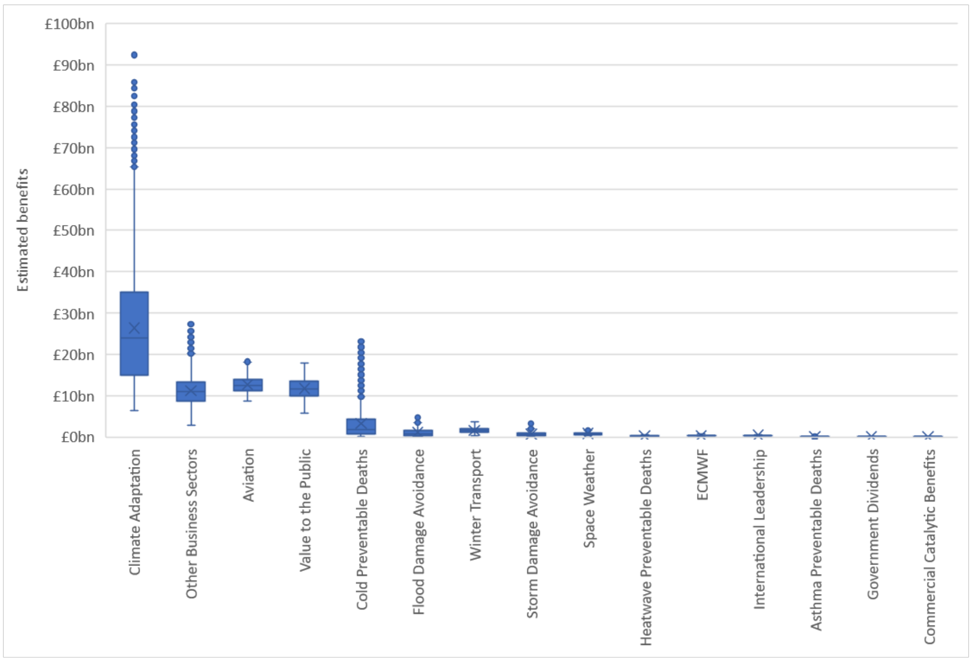
Table 18 Sensitivity analysis results - by benefit stream - 'Basic' Met Office scenario

Benefit stream	Central estimate	Sensitivity analysis results		
		Median	Lower 90%	Upper 90%
Aviation (UK only)	£5.5bn	£5.3bn	£5.3bn	£5.8bn
Climate Adaptation and Mitigation	-	-	-	-
Value to the Public	£7.4bn	£5.7bn	£5.7bn	£10.5bn
Other Business Sectors	£6.9bn	£4.1bn	£4.1bn	£11.5bn
Met Office Revenue*	£2.3bn	£2.3bn	£2.3bn	£2.3bn
Cold Preventable Deaths	£1.2bn	£0.1bn	£0.1bn	£7.2bn
Winter Transport	£1.0bn	£0.4bn	£0.4bn	£1.8bn
Flood/Storm Damage Avoidance	£0.4bn	£0.1bn	£0.1bn	£3.0bn
Space Weather	-	-	-	-
International Leadership	-	-	-	-
ECMWF	-	-	-	-
Heatwave Preventable Deaths	£0.1bn	<£0.1bn	<£0.1bn	£0.5bn
Government Dividends	-	-	-	-
Asthma Preventable Deaths	<£0.1bn	<£0.1bn	<£0.1bn	£0.1bn
Commercial Catalytic Benefits	-	-	-	-
Total present benefits	**£24.6bn**	**£20.7bn**	**£20.7bn**	**£37.8bn**

Note: The graph shows the results of Monte-Carlo simulations, for each monetised benefit stream, around the total estimated present benefits to the UK, over the next decade, associated with the Met Office's activities. The graph is based on 10,000 simulations. (*) Revenues are excluded in the estimates of the return on public investment as i) commercial contract revenues are a transfer payment from UK businesses to the Met Office and so have a net-zero benefit to the UK taxpayer, and ii) non-commercial Met Office revenue is predominantly public funded and so while it is a benefit to the Met Office it is a cost to the UK taxpayer.

Source: London Economics

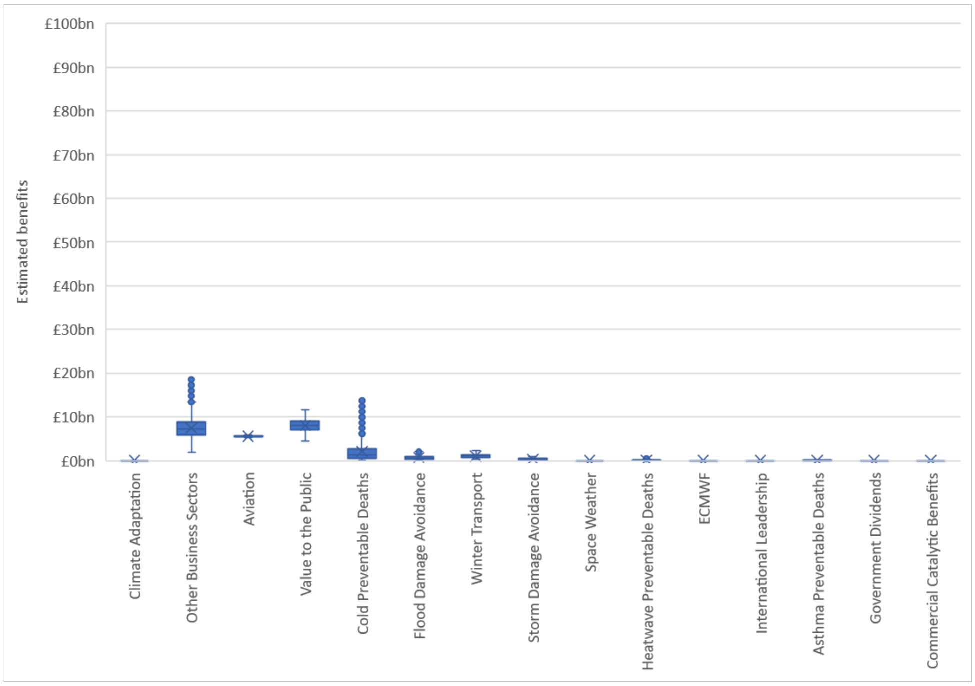
Figure 34 Sensitivity analysis – boxplots of simulation results - 'Existing' Met Office base case



Note: The graph shows, for each benefit stream under the 'Existing' Met Office baseline scenario, the boxplots of the results of the simulations undertaken. Boxplots are a way to visualise the uncertainty implied by the simulation results. They show the range of benefits that half of simulations resulted in (represented by the central box, with the bottom of the box representing the 25th percentile and the top of the box the 75th percentile), the median (represented by an 'X'), and any outliers representing large, estimated benefits occurring only in a smaller number of simulations (dots).

Source: London Economics

Figure 35 Sensitivity analysis – boxplots of simulation results - 'Basic' Met Office



Note: The graph shows, for each benefit stream under the 'Existing' Met Office baseline scenario, the boxplots of the results of the simulations undertaken. Boxplots are a way to visualise the uncertainty implied by the simulation results. They show the range of benefits that half of simulations resulted in (represented by the central box, with the bottom of the box representing the 25th percentile and the top of the box the 75th percentile), the median (represented by an 'X'), and any outliers representing large, estimated benefits occurring only in a smaller number of simulations (dots).

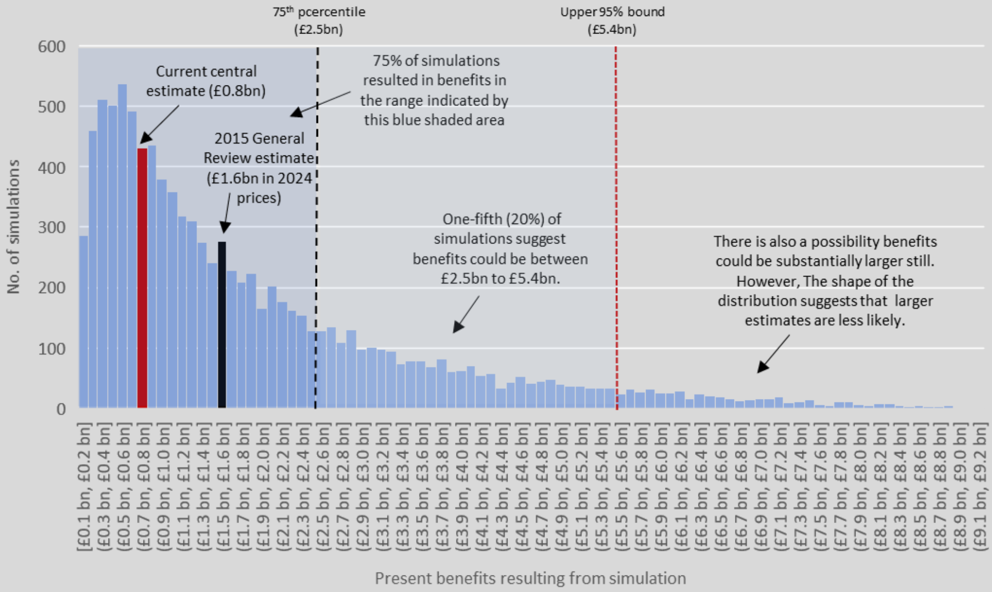
Source: London Economics

Box 26 Sensitivity analysis for avoided flood and storm damages ('Existing' Met Office)

Examining the implied distributions from the sensitivity analysis for all benefit streams would be very space intensive. However, given the changes in the estimation of flood and storm damages, and the resulting lower aggregate benefit estimates in the central case, it is useful to examine the implied distribution for flood and storm (Figure 36) benefits more closely. This shows that:

- While central benefit estimates in this study are lower than those from the previous 2015 General Review, it is entirely possible that actual benefits are of a similar magnitude to those estimated in the previous study.
- Indeed, there is a potential for benefits to be substantially larger still. The 95% upper bound suggests benefits could be as large as £5.4bn over the next decade, more than three times as large as benefits implied by the previous methodology. However, the long-right tail implies that larger benefits of this magnitude are much less likely.
- 75% of simulations resulted in combined storm and flood benefits of up to £2.5bn. This suggests benefits are much more likely to be in this range. This is further highlighted by the height of the bars in this area of the distribution which represent the number of simulations resulting in benefit estimates in the range indicated under each bar.
- Higher bars indicate it is more plausible that benefits are in the range associated with these bars. This means that, while benefits could be as high (or higher) as implied by the assumptions used in the 2015 General Review, in light of new evidence (lower estimates of average flood damages and lower uplifts), this is less likely than previously assumed.

Figure 36 Sensitivity analysis results – flood and storm damages (baseline scenario)



Note: The graph shows the results of Monte-Carlo simulations around the estimated present benefits of avoided UK flood and storm damages attributable to the Met Office, over the next decade. The graph is based on 10,000 simulations. The central results of this study fall within the red shaded bar. The central results of the previous 2015 General Review (in 2024 prices) fall within the black shaded bar. The red- and black-dashed lines show the 75th, and 95th percentile estimates from the simulations. The percentiles show that i% of simulations resulted in benefits less than or equal to those indicated by the ith percentile. The blue shaded area shows that 75% of simulations resulted in benefits in this range. 95% of simulations resulted in benefits between up to the 95% upper bound. A small proportion, 5%, of simulations resulted in benefits higher than the upper 95% bound.

Source: London Economics

LE
London Economics

Somerset House, New Wing, Strand
London, WC2R 1LA, United Kingdom
info@londoneconomics.co.uk
londoneconomics.co.uk
X: @LondonEconomics
+44 (0)20 3701 7700