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Natural Environment Research Council

A report on the economic and social impact of selected NERC-funded research

December 2015



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1 Introduction

1.1 Study scope

The Natural Environment Research Council (NERC) was established in 1965 to be the lead funder of independent research of environmental science in the UK. NERC's founding Royal Charter recognises the importance of environmental research that allows the UK to deliver innovation and growth with responsible environmental management. NERC currently supports over 1,000 research projects at 55 universities and 20 research institutes. It has focused on generating basic, strategic and applied research, as well as improving UK productivity, via the training of skilled PhD students (and, historically, Masters students) and collaboration with industry and policymakers. NERC has also improved public awareness and dialogue in relation to its research.

NERC currently supports six Research Centres:

- The British Antarctic Survey;
- The British Geological Survey;
- The Centre for Ecology & Hydrology;
- The National Centre for Atmospheric Science;
- The National Centre for Earth Observation; and
- The National Oceanography Centre.

NERC draws on both public and private funding sources to support its researchers, with the Department for Business, Innovation and Skills (BIS) being the primary public funding body. As such, it is important for NERC to demonstrate accountability to both BIS as well as HM Treasury for the impact of the public funds it receives and distributes.

NERC has commissioned Deloitte to provide a robust and independent assessment of the different impacts some of its research activities have had on the UK economy and society. Over July and August 2015, Deloitte has assessed the economic and wider impacts of NERC's research in four areas of environmental research and produced two-page summary documents for each. The areas of research were agreed with NERC and covered:

- Stratospheric ozone depletion;
- Air pollution;
- Sustainable energy generation and resource extraction;
- Risk identification and analysis.

The research themes were chosen as they represent some of the most prominent areas of NERC's research activities, as well as areas in which their research has led to known material impacts in societal and economic benefits.

Each two page summary contains elements of quantification and summary analyses of Deloitte's work. This document supports the summaries by providing more detail on the methodologies employed. It focuses on the assumptions made and techniques used by Deloitte to identify and quantify (where possible) the material contribution NERC research has made to positive economic and societal outcomes.

1.2 Study method

For each of the four thematic areas, a discrete impact assessment has been undertaken by Deloitte. Each impact assessment is independent in that it does not consider impacts outside the remit of each topic area.

Evidence on each area's economic and wider impacts is based on an analysis of individual Research Excellence Framework (REF) submissions and case studies, reports by NERC, the original scientific research papers and interviews with researchers and industry experts. The collected evidence was then applied to a logic framework (see Chapter 2) to trace scientific inputs to outputs to outcomes. Individual chapters set out the precise assumptions used. In particular, the chapters capture the discussions undertaken with staff from each of the six Research Centres to determine the materiality of NERC's contribution to the underlying science and subsequent impacts.

The impact analysis undertaken and tools and techniques applied have drawn on the principles of appraisal and evaluation as set out in the Government's Green and Magenta Books. However, given time and resource constraints, the analysis is not intended to be fully compliant.

1.3 Acknowledgements

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1.4 Limitations of the analysis

The scope of these four impact assessments is limited to the four thematic areas agreed between NERC and Deloitte. As a result, impacts associated with other areas of NERC research are not considered and those impacts presented cannot be interpreted as being the total contribution of NERC science.

In addition, primary research and data collection to evaluate impact of individual research projects fell outside the scope of this project. As such, identified impacts and their quantification are based on existing evidence and discussions with stakeholders – data and evidence received has not been validated by Deloitte. The suite of impacts identified and assumptions used are therefore guided by the existing, available evidence, not necessarily comprehensive, but should be treated as indicative.

Equally, it should be noted that while NERC-funded research is making a material contribution to achieving impacts in each of the four thematic areas, this study recognises that other research and funding bodies are also contributing to the knowledge stock in these areas. This study takes a conservative approach of only quantitatively apportioning impacts to NERC when there is clear evidence to demonstrate a causal link and measure additionality.

On a technical note, where data is available, the quantification of impacts accounts for both costs and benefits and is presented as net impacts. However, in some instances the cost imposed by policies supported by NERC research is not available and must be recognised as a gross impact.

Further, the figures quoted on NERC funding for research in each thematic area should be considered indicative and not exact, due to both availability of funding data and inherent overlap in thematic areas.

2 Impact framework

2.1 Framework used for this study

A conceptual framework was developed to capture the number of different ways in which NERC research can generate economic, societal, environmental and political benefits to the UK and beyond.

Figure 1 Conceptual Framework of NERC-funded Research Impact



Source: Deloitte Analysis and NERC

For each NERC science activity, the (direct) pathway to impact was identified. These are direct impacts in the sense they are being generated by NERC researchers themselves. These include academic articles, data, software, presentations and advice, patents and so forth. For each activity, the pathway to impact that was generated was then considered, e.g. how policy advice subsequently generated economic or political benefits.

In addition to these direct pathways to impact, NERC research also indirectly generates benefits through the impact it has on other stakeholders within the public and private sectors, rather than its own researchers directly. For example, NERC research can effect central government regulation decisions, which can then generate a number of different benefits. Similarly, NERC-funded research disseminated in the media may influence consumer's expectations and change their behaviour, generating economic, environmental or societal benefits.

This framework was operationalised for the purpose of this study by drawing on a selected number of research case studies in each of the four thematic areas and understanding how they supported benefits through both direct and indirect pathways. The outcomes and impacts stemming from each of the research case studies were grouped in sub-categories to define a specific list of impacts, to which various pieces of research have contributed to.

For example, a number of NERC-funded research projects have contributed to improving air quality in the UK. While only one impact was measured (higher air quality), it is acknowledged through this methodology that multiple

pieces of research contributed to this impact. An example of how this process was applied to air pollution is illustrated below.



Figure 2 Example of output to impact mapping for Air Pollution

Source: Deloitte analysis based on REF case studies and NERC research case studies

The metrics used to measure impact vary depending upon the impact being measured and the specific thematic area to which it relates. As much as possible, a monetary value, whether this be associated with cost savings, gross value added (GVA) or earnings, has been used.

2.2 Quantitative and qualitative methodology assumptions

The methodology assumptions applied to the quantification of impacts is contextual to each of the four thematic areas and the impact being quantified. While details of specific assumptions are provided in Chapters 3-6, below is a summary of those general assumptions that have been applied across all impact quantification.

- All prices are stated in 2015 values, corrected using consumer price index (CPI) data from the ONS.
- Present values have been calculated using a discount rate of 3.5% (as per Green Book guidance) unless specified otherwise.
- Impacts are presented at the UK level where possible, however this is dictated by the nature of the research and impact, some of which are country or region specific and this is made clear in the assumptions.
- A conservative approach for attributing impacts (and inferring causality) has been taken. Where evidence to
 justify causality is not available, the material contribution that NERC research has made leading to impacts has
 been detailed in the narrative and substantiated by evidence from case studies.

While this study seeks to understand the full impact of NERC's research in the four thematic areas, quantitative measurement techniques can only be applied to a select number of impacts. There are qualitative impacts that NERC-funded research also delivers and, where possible, they are discussed within the respective section of each thematic area chapter (Chapters 3-6 of this report). These range from strengthening the UK's international reputation for excellence in scientific research, strengthening its soft power impact abroad, to fostering lasting networks and collaboration between NERC-funded researchers and other institutions.

2.3 Structure of impact analysis methodology

Chapters 3-6 present a detailed account of the methodology used to assess the impact of each of the four thematic areas. For consistency, each Chapter follows the same structure capturing the following components of the methodology used:

- **Inputs and outputs**: this section deploys the conceptual framework outlined above to identify the inputs and outputs that led to impacts. Inputs include the funding and resources that NERC draws on to produce its research outputs. Outputs describe the findings, data and tools that NERC research has developed. This section is descriptive and the quantification of these impacts follows in the proceeding section on quantification.
- **Beneficiaries and impacts**: this section identifies the people and organisations who are the beneficiaries of NERC research. It also identifies the specific areas in which NERC-funded research has had an impact. For example, impact areas can range from health and environmental benefits to economic benefits from additional private sector investment.
- Quantification of impacts: this section sets out the methodology behind the quantification of impacts (where this has been feasible). It discusses the materiality of NERC's research in contributing to the identified impacts. Establishing the materiality of NERC's contribution to the impact provides the link between NERC research and the quantification of each impact.
- **Qualitative impacts**: For some impacts, data is not available that allow for the quantification of that impact. When this is the case, these impacts are discussed qualitatively in this section.

3 Stratospheric ozone depletion

Ozone depletion - NERC's research protects lives and the environment

The ozone layer naturally protects the planet from harmful ultraviolet (UV) light. NERC scientists were the first to discover a process of stratospheric ozone depletion high in the Earth's atmosphere that left unchecked could cause serious harm to the planet. NERC's research was crucial to the case for, and ratification of, the Montreal Protocol in 1987, which set out to curb the use and production of man-made ozone-depleting substances. The Montreal Protocol is now widely recognised as one of the most successful international agreements of its kind.

"For the first time ever, rich and poor nations alike set out together to save our planet from a serious danger" (Margaret Thatcher, 1991).

The resulting reduction in ozone-depleting substances has contributed to a reduction in skin cancer incidence and UV-induced crop damage in the UK, as well as strengthening soft power, improving public debate and the longevity of infrastructure. On average NERC pays grants of £1.5 million annually towards ozone related research. In the UK, the cost savings from ozone research are estimated to be around £1.3bn annually. It is estimated that in the absence of NERC's investment in monitoring activities the ozone hole would have not been discovered for another 5 to 10 years; the additional benefits over this period to the UK from the NERC research is estimated to be between £6.1bn and £11.2bn. Consequently, this funding has...



3.1 Overview

NERC's initial and most widely recognised contribution to stratospheric ozone depletion science was the discovery, in 1985, of the Ozone Hole by researchers Joe Farman, Brian Gardiner and Jonathan Shanklin. This discovery was based on 30 years' worth of measurements from instruments at the British Antarctic Survey (BAS) Halley Research Station. Their work gained international attention and led to a considerable acceleration in the ratification of the Montreal Protocol. This protocol phased out the use of ozone depleting substances globally, averting an increase in ground level UV exposure that would have had significant negative impacts on public health and the economy. Since then, NERC has been funding leading scientific research related to the ozone layer, both at BAS and in universities throughout the UK. This research continues to generate benefits to the UK.

3.2 NERC inputs and outputs

The inputs that supported the discovery of the Ozone Hole and continued monitoring is the amount of funding BAS has dedicated to research in this area. BAS estimates that from 1957 (when it began monitoring the ozone layer) to the present day, £14.1m (2015 prices) has been spent on ozone layer related research in the Antarctic. Additionally, research grants identified by NERC as relating to the ozone layer paid to researchers in the UK have averaged £1.5m annually over the ten years from 2004 to 2014.

The most significant research output resulting from NERC research funding was the publication *Large losses of total ozone in Antarctica reveal seasonal CIOx/NOx interaction* in Nature, in May 1985. This publication, together with other scientific outputs (such as the Nobel Prize winning research of Prof Crutzen, Molina and Rowland) established the need for a broad, international agreement to phase out the use of ozone depleting substances in order to avoid damaging the ozone layer further and allow it to repair. The empirical evidence provided by NERC quickly led to the ratification of the Montreal Protocol in 1987.

Since 1985, NERC remained involved in research related to ozone depletion and monitoring. This research has had a continued policy impact as well as making a positive contribution to the public debate. Professor John Pyle of the University of Cambridge Chemistry Department and his team have been frequent recipients of NERC research grants, and John Pyle himself has been a lead-author for periodic assessments of ozone depletion for the World Meteorological Organisation since 1985. This has had a direct policy impact by supporting the case for a number of amendments to the Montreal Protocol to strengthen its conditions, and the work of Prof Pyle and the wider team has appeared numerous times in the media. In addition, NERC-funded researchers at the University of East Anglia have recently worked with researchers at the University of Frankfurt to develop new means of identifying illegal CFC use, which offers the potential to increase compliance with the terms of the Montreal Protocol by identifying breaches of its terms.

3.3 Beneficiaries and impact areas

The discovery of the Ozone Hole in 1985 led directly to the ratification of the Montreal Protocol, which provided benefits globally as well as at the UK level. Subsequent work by NERC-funded researchers to measure and understand ozone levels also generated benefits, through either amendments of the Protocol's terms which have strengthened it or by informing the public debate via publications in the media.

Benefits from reduced exposure to UV, made possible by NERC's research via the Montreal Protocol and its amendments, fall within three areas:

- Health benefits: Excess exposure to UV radiation is a contributing factor to a number of health problems including skin cancer, cataracts¹ and suppression of the immune system². These conditions impose costs to national health systems and impact negatively on the sufferer's quality of life and economic output. The Montreal Protocol has led to reduced UV levels worldwide, reducing the health costs associated UV exposure.
- Economic benefits: UV radiation can also negatively impact crop yields in some plant species and damage certain building materials (such as synthetic polymers). Both of these lead to businesses incurring losses, or facing adaption costs to mitigate these effects. A reduction in UV exposure reduces the cost to businesses of having to mitigate these effects.
- Political and societal benefits: The Montreal Protocol remains the most widely ratified UN treaty³ and showcases the efforts of the underlying British research. NERC-funded researchers such as Prof John Pyle also contribute positively to the public debate around ozone depletion and climate change, increasing people's understanding of the importance of these issues, and generating support for more informed policies. Finally, NERC-funded science diplomacy helps boost Britain's position in the world through expert advice and representation within the UK Antarctic Treaty delegation.

3.4 Quantitative analysis

Quantifying NERC's contribution to the benefits requires a counterfactual case against which to compare. This case has been developed based on discussions with BAS to understand the time lag of when the Ozone Hole might have been discovered in BAS's absence. The details of this counterfactual case are set out below (section 3.4.1).

Upon establishing the counterfactual case, information from existing sources, including the UN, US Environmental Protection Agency (EPA) and the UK Health and Safety Executive (HSE), have been used to quantify the negative impacts of skin cancer and UV induced reductions in crop yields. The details of how these sources quantify impact and how this information was used in this analysis is presented in sections 3.4.2-3.4.4.

¹ Roberts (2011), Ultraviolet radiation as a risk factor for cataract and macular degeneration

² Schwarz (2005), Mechanisms of UV-induced immunosuppression

³ UNEP news centre (2012), Most widely ratified treaty in UN History marks 25th anniversary

3.4.1 The materiality of NERC's impact

NERC's primary contribution in this area has been the findings that directly led to the ratification of the Montreal Protocol. The materiality of NERC's impact in generating the benefits that stem from the Montreal Protocol are established on the basis of the counterfactual situation. The counterfactual considers what would have happened if NERC did not find the Ozone Hole.

Consultations with BAS indicated that, given the research and monitoring activities of other countries, such as Japan's research station Syowa and US efforts to monitor ozone levels via satellite, the ozone hole could have gone undiscovered for between 5 and 10 years if NERC had not made its discovery in 1985. This would have incurred a 5 to 10 year delay in the ratification of the Montreal Protocol to curb the emission of ozone depleting substances and avert an additional reduction in ozone levels.

Understanding the implications of a delayed Montreal Protocol is complicated, due in part because research conducted to date has only considered the counterfactual situation of 'no Montreal Protocol' rather than a delay in the Protocol. A delay in the Montreal Protocol would imply that the effects of UV exposure on human health (which are delayed and do not appear immediately after exposure) would incur additional health costs further into the future.

Recognising the limitation that no study to date has examined the counterfactual situation of a 5-10 year delay in the Montreal Protocol, a number of assumptions were applied to secondary sources (detailed below) to construct the 5-10 year delay counterfactual. Firstly, we use the United Nations Environmental Programme (UNEP) assessments⁴ of stratospheric ozone depletion, which provides details of the benefits of the Montreal Protocol and its amendments relative to a 'do nothing' scenario where the ozone layer had been allowed to deplete unchecked. This includes reference to van Dijk et al⁵ which provides details on skin cancer incidence rates that have been used to develop the counterfactual in this analysis. We know of no data which provides estimates of the magnitude of the benefits arising from the Montreal Protocol relative to a scenario of it being delayed for a period of time.

In light of this limitation, we provide an indicative estimate of the magnitude of NERC's impact with the data available using a 5 to 10 year net present value (NPV). This time period is in line with BAS's assessment of the extent to which its activities hastened the discovery of the ozone hole and has been applied to findings such as those by the EPA and the UN against a 'do nothing' scenario where the Montreal Protocol was not passed. In the absence of clarity as to when this benefit is realised, it has been presented over a five year period (2015-2020) and a ten year period (2015-2025) and discounted at 3.5%.

The quantification methodology below explains the data sources and assumptions that have been used to arrive at annual impacts in terms of both skin cancer and crop damage for 2015, were the Montreal Protocol not passed. This estimate makes use of the best available data found through an extensive literature review to provide an indication of the magnitude of the effect that NERC funding might have had at the UK level.

3.4.2 Skin cancer quantification (healthcare costs)

Modelling of the reduction in cases of skin cancer resulting from the Montreal Protocol assumes that there will have been 14% fewer cases per year by 2030.⁶ A figure for 2030 has been used in the absence of any alternative figures for other years, and therefore the impact should be considered indicative. Using a forecast of the costs to NHS England of skin cancer treatment⁷, and the population share of England within the UK (84%)⁸, the annual costs to the NHS of skin cancer treatment in the UK has been estimated to be £220m at 2015 prices. This has been calculated by taking the estimated costs (at 2008 prices) for skin cancer care in 2008 of £109m and 2020 at

⁴ UNEP (2014), Environmental effects of ozone depletion and its interactions with climate change: 2014 assessment

⁵ van Dijk et al (2013), Skin cancer risks avoided by the Montreal Protocol – Worldwide modelling integrating coupled climate-chemistry models with a risk for UV

⁶ van Dijk et al (2013), Skin cancer risks avoided by the Montreal Protocol – Worldwide modelling integrating coupled climate-chemistry models with a risk for UV

⁷ Vallejo-Torres et al (2008), Measuring the current and future costs of skin cancer in England

⁸ ONS (2014), Overview of the UK population

£185.5m and assuming linear development between years, to arrive at £153.6m for 2015, or £188.0m once corrected to 2015 prices. Finally, given that this cost covers only the costs to the NHS England, it have been divided by 84% to provide an estimate for the costs at the UK level of £223.6m.

In line with the estimates endorsed by the UN Environmental Programme, one of the benefits of the Montreal Protocol is a 14% reduction in the incidence rate of skin cancer by 2030. It has been assumed that this reduction is uniform across years (in the absence of any additional information) meaning that the annual saving in terms of healthcare costs for skin cancer care is estimated to be £36.4m, or between £170.1m and £313.4m on a 5 to 10 year NPV basis at 2015 prices discounted at 3.5%.

3.4.3 Skin cancer quantification (human costs and lost output)

In addition to healthcare costs, skin cancer also imposes costs to those suffering it, and affects the economy through reducing its potential output. The UK Health and Safety Executive (HSE) provides a value of a life for the purposes of assessing the costs and benefits of safety measures of £1.3m (at 2005 prices), or £1.8m (at 2015 prices).⁹ This includes healthcare costs and to avoid double counting with the healthcare savings identified above, the average cost of treatment for a case of malignant melanoma¹⁰ of £3,200 at 2015 prices (the form of skin cancer most likely to result in death) has been removed to arrive at a benefit of £1.8m per life saved, at 2015 prices.¹¹

The number of cases of malignant melanoma in the UK in 2015 is estimated to be 11,129. This has been informed from the fact that the number of cases in England in 2001 was 6,006 and the number of cases in England in 2020 is estimated to be $10,550^{12}$ with the assumption that the number of cases will develop linearly over time and that dividing the figure in England by 84% provides an estimate of the number of cases in the UK. Given mortality rates from this type of cancer of 16.1%,¹³ the estimated number of deaths from malignant melanoma is 1,791. Assuming that the Montreal Protocol has resulted in a 14% reduction in cases of melanoma, this implies 292 fewer deaths occur each year and a saving of £520m is achieved annually (given the impact per life has been estimated to be £1.8m). This implies cost savings of between £2.4bn and £4.5bn on a 5 to 10 year NPV basis at 2015 prices, with 3.5% discounting.

3.4.4 Crop damage quantification

Valuing the negative economic impact to the agricultural sector from a decline in crop yields resulting from NERC's research and funding would require an assumption regarding the impact of increased UV exposure to the mix of crop species grown within the UK. It would also require an assumption regarding the adaption measures that farmers might have taken in the event that UV levels increased. Finally, the level to which yields of different crop species are affected by UV exposure varies considerably,¹⁴ and can range from very limited effects to reductions in yield of as much as 20-25% for some species¹⁵. This means that it is difficult to determine accurately the extent to which the overall agricultural output of a country would be affected. For these reasons, it is considered prohibitively difficult to develop an estimate specific to the UK and instead, a figure from a secondary source has been used from a country at a similar latitude to the UK, in the belief that it provides a close approximation of the likely impact.

In its assessment of the benefits and costs of the Clean Air Act,¹⁶ which included amendments related to the Montreal Protocol's terms, the US Environmental Protection Agency stated that a 7.5% UV-related decrease in crop harvests across the US will be averted as a result of the Act. Using this figure as a basis for our assumption, and in the absence of any other detail as to the impacts on crop yields of Montreal Protocol in the UK, it is assumed that this figure could also be applied to the UK to generate an indicative estimate.

⁹ HSE website, www.hse.gov.uk/risk/theory/alarpcheck.htm (Accessed July 2015)

¹⁰ Vallejo-Torres et al (2008), Measuring the current and future costs of skin cancer in England

¹¹ Note that this does not make a difference at the level of one decimal place, but that it has been reflected in the calculations themselves ¹² Moller et al (2007), the future burden of cancer in England

¹³ Cancer Research UK (2014), UK cancer incidence 2011 and mortality 2012 summary

¹⁴ Teramura, Sullivan & Lydon (1990), Effects of UV-B radiation on soya bean yield and seed quality: a 6 year field study

¹⁵ Fiscus & Booker (1995), Is increased UV-B a threat to crop photosynthesis and productivity?

 $^{^{\}rm 16}$ US EPA (1999), The benefits and costs of the Clean Air Act 1990 to 2010

In 2013, the UK's crop output was £9.5bn¹⁷ at current prices. This is equal to £9.8bn at 2015 prices, meaning that the impact of avoiding a 7.5% decrease would be in the region of £740m annually, or £3.4bn to £6.4bn on a 5 to 10 year basis at 2015 prices, with 3.5% discounting.

3.4.5 Overall

The impacts of skin cancer and crop damage can be estimated using the available information from third party sources. Overall, the magnitude of the impact across these areas is estimated to be £1.3bn annually or between £6.1bn and £11.2bn over a 5 to 10 year period (all expressed at 2015 prices, and discounted at 3.5%).

3.4.6 Assessment of costs

Within the timeframe of this analysis, it has not been possible to identify the costs to the UK of the implementation of the Montreal Protocol and its subsequent amendments. It is possible, however, to identify the funding from NERC that has been spent on ozone monitoring from the Antarctic since 1957 when it began, and the annual research grants paid towards ozone related research. By BAS's own estimate, the spending on Antarctic monitoring of the ozone layer since 1957 has been £14.1m (at 2015 prices). Separately, NERC data on grants paid to those engaged in ozone related research has amounted to £1.5m annually over the 10 years to 2014.

3.5 Qualitative analysis

In addition to impacts that can be quantified, NERC funding has resulted in a number of impacts that could be quantified were further information available as well as qualitative benefits. For example, UV exposure is also linked to the development of cataracts and negatively impacts the immune system. This suggests that further savings to the NHS occur as a result of the Montreal Protocol. In addition, certain building materials are degraded more quickly as a result of UV exposure, meaning that the reduction in ground level UV levels also increases the life expectancy of some structures and avoids the need for defensive costs to be incurred.

It was also noted in discussion with NERC Research Centres that ozone research has increased Britain's scientific reputation, which has given it a more advantageous position within the framework of the Antarctic Treaty as a leading scientific contributor. This increased soft power resulting from NERC-funded research increases positive perceptions of Britain and confers benefits upon it that are significant in international negotiations, such as those around the Antarctic Treaty.

¹⁷ Defra (2015), Agriculture in the United Kingdom, 2014

4 Air pollution

Air pollution - NERC's research leads to improved air quality at home and abroad

Air pollution is a mixture of gases and particles that are emitted into the Earth's atmosphere largely by man-made processes, in particular, through the combustion of fossil fuels. Air pollution is a serious issue: in the UK it causes premature deaths (29,000 per year on average¹), reductions in agricultural yields and damage to buildings, woods, and freshwater ecosystems.

While the emission of some air pollutants began to decline in the 1980s, the introduction of more stringent air pollution policies between 1987 and 1990 accelerated this decline and widened the types of air pollutants affected. NERC research directly contributed to this reduction through:

- Providing prominent scientific research that led to international abatement agreements, which in turn, strengthened the UK's scientific and political leadership informing policies abroad; and
- Developing new data and tools enabling regulators, local authorities and the general public to better mitigate health and environmental impacts.

This decline in pollution has generated a range of benefits including:



4.1 Overview

NERC funding has developed the evidence base that supports national and international agreements to reduce harmful pollutants, such as sulphur dioxide. It has also led to improved air quality, reducing the incidence of negative health and ecological impacts related to air pollution.

NERC-funded research has played a central role in developing the policies that have led to this reduction in emissions, beginning with its contribution to the Convention on Long-Range Transboundary Air Pollution in 1979, dramatically reducing the UK's sulphur dioxide emissions in particular. More recently it has informed policies to limit Mercury use and the ban of HBCD¹⁸, a toxic chemical flame retardant used in some building materials.

Environmental legislation, policies and regulations that NERC and other organisations have contributed to include:

- The 1979 UN Convention on Long-range Transboundary Air Pollution (CLRTAP): the UK adopted this convention in 1982, which was the first international legally binding instrument to deal with air pollution on a regional basis. Once the CLRTAP convention was established, protocols were created by the member states within this agreement (outlined below).¹⁹
- The 1988 Sofia Protocol concerning the Control of Nitrogen Oxides: the UK ratified this protocol in 1990, which requires the country to control or reduce emissions of nitrogen oxides and introduce pollution control measures for major sources of emissions.
- The 1991 Geneva Protocol concerning the Control of Emissions of Volatile Organic Compounds: the UK ratified this protocol in 1994, which requires countries to reduce VOCs, a major pollutant responsible for ground-level ozone.
- 1993 Clean Air Act: an act to consolidate the Clean Air Acts of 1956 and 1968

¹⁸ Hexabromocyclododecane (HBCD) is a brominated flame retardant that is used in some building materials which damages human health if inhaled, and is bioaccumulative.

¹⁹ Note that member states have the choice whether or not to adopt protocols created under the CLRTAP agreement. If states do adopt a protocol, there is usually a lag time between adopting and ratifying a protocol.

- The 1994 Oslo Protocol on Further Reduction of Sulphur Emissions: the UK ratified this protocol in 1996, which sets emission ceilings until 2010 and beyond. In addition, it requires countries to reduce sulphur emissions through the use of energy efficiency, renewable energy and to do so in the most cost effective way.
- **UK Environmental Act 1995**: an Act of UK Parliament which established the Environment Agency and Scottish Environment Protection Agency, required the development of a National Air Quality Strategy (subsequently published in 1997), and incorporates European laws on reduction of emissions for pollutants including sulphur dioxide, nitrogen and particles.
- **The 1998 Aarhus Protocol on Heavy Metals**: the UK ratified this protocol in 2005, which requires countries to reduce emissions for cadmium, lead and mercury below their levels in 1990, especially from industrial sources.
- **1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone**: the UK ratified this protocol in 2005, which sets national emission ceilings from 2010 up to 2020 for sulphur, nitrogen oxides, VOCs and ammonia.
- **2007** Air Quality Strategy for England, Scotland, Wales and Northern Ireland: this updated Strategy sets a new reduction programme for particles (PM_{2.5})²⁰ and also establishes the link between climate change and air pollutants.

These policies have greatly reduced emissions of pollutants including sulphur dioxide, PM_{2.5}, Volatile organic compounds, Nitrogen oxides, PM₁₀²¹ and Ammonia.

In supporting the development of these policies, NERC-funded research has contributed to lowering the overall levels of air pollution in the environment, leading to:

- A reduction in the impact of pollution on human health, improving quality of life and reducing illness and death;
- Protecting the environment and supporting the restoration of habitats, preserving wildlife and the quality of the living environment;
- Reducing damages to buildings from air pollution, reducing the required mitigation costs and freeing time and money for more productive uses.

4.2 NERC inputs and outputs

NERC estimates that it spends approximately £3m a year on research and projects related to air pollution.²² This spend has supported a number of research projects, which, for the purpose of this analysis, have been grouped into three specific areas of focus: 1) research leading to international agreements on emission reduction, 2) development of data and tools to mitigate air pollution, and 3) demonstrating UK international leadership in managing air pollution.

The sections below highlight the key outputs from NERC-funded research in each of these three categories.

4.2.1 Research which leads to international agreements on emission reduction

NERC has funded research into a number of individual pollutants which have led to international agreements and policies.

The UK joined the 1979 UN Convention on Long-Range Transboundary Air Pollution (CLRTAP). Although it did not ratify its first protocol under CLRTAP until 1990, NERC's Centre for Ecology and Hydrology (CEH) made a number of important contributions to the Convention before and after this date.

• **Pioneering the first truly international project on acid rain under CLRTAP**: NERC collaborated extensively with Scandinavian scientists, the EU, and the Royal Society on the Surface Waters Acidification Programme (1983-1990). The findings fed into the CLRTAP's second protocol to limit sulphur emissions (Oslo, 1994) and

 $^{^{20}}$ PM2.5 refers to particulate matter that is less than or equal to 2.5 micrometres.

²¹ PM10 refers to particulate matter that is less than or equal to 10 micrometres.

²² NERC (2014), Impact report 2014: the business of the environment

the first sulphur emissions protocol signed by the UK²³. When the original research findings were first presented in 1990, then Prime Minister Margaret Thatcher recognised the quality of the programme, stating at the conference banquette, "above all, your work has shown how important good and thorough science is if action is to be effective." In the same speech she also stated announced a £6bn investment plan to reduce air pollution stating, "tonight the UK will meet the commitment that it has solemnly accepted to reduce acid emissions and we shall do so by embarking on a major programme of investment to protect the environment."

- Leading the ICP on Natural Vegetation and Crops: CLRTAP established the Working Group on Effects to provide the on-going scientific information on geographic impacts of major air pollutants. The Working Group on Effects has six International Cooperative Programmes (ICPs) which draw on international scientific research programmes, reviewed annually, to discuss the current and future needs of the Convention. In 1987 the ICP on Natural Vegetation and Crops was established, led by the UK and based at NERC's CEH. Today over 200 scientists from 35 countries participate in the programme which studies the effect of ozone pollution on crops and vegetation.²⁴
- Providing UK Critical Load data to CLRTAP's ICP Modelling and Mapping: The first European map of critical loads of sulphur-based acidity that included national contributions was produced by the Mapping Programme in 1991 and is regularly updated today by the ICP Modelling and Mapping.²⁵ CEH scientists developed the first acidity critical load maps for the UK which fed into the Mapping Programme output. Since 1994, a CEH scientist has been Head of the UK National Focal Centre for Critical Loads Modelling and Mapping representing the UK at meetings of the ICP Modelling and Mapping.²⁶

In addition, a NERC-funded knowledge exchange programme, 'Integrating Knowledge to Inform Mercury Policy' provided policy guidance and evidence to Defra and the UNEP as they developed the Minamata Convention. The Minamata Convention was adopted in 2013 by 140 countries who commit to reduce their use of mercury and thereby reduce the negative impacts that mercury emissions have globally. In addition, NERC-funded research was the first to measure the prevalence of HBCD (a toxic chemical used as a flame retardant) in indoor dust, leading to its inclusion in the 2013 Stockholm Convention on persistent organic pollutants which requires countries to eliminate the use of HBCD. The Stockholm Convention aims to protect human health and the environment from Persistent organic Pollutants (POPs). POPs are chemicals that can stay in the environment for long periods, accumulate in the tissue of humans and wildlife, and impact negatively on human health and the environment.

NERC scientists at CEH authored several chapters of the European Nitrogen Assessment (ENA)²⁷, used by UK and European governments to inform nitrogen abatement policies.

4.2.2 Development of data and tools to mitigate air pollution

NERC funding helps to support a number of initiatives that model and monitor air pollution. For example, CLEARFLO²⁸ (Clean Air for London) has established air pollution monitoring sites throughout the city which provide near real-time measurements of a number of pollutants, as well as historical data on which to base research and modelling. This data is used by scientists to further study air pollution in London and is also incorporated into the London Air Quality Network website which provides air quality data used by Local Authorities.

Another project partially funded by NERC is the Air Pollution Information System²⁹ (APIS) which provides upper limits for different habitats, locations and pollutants throughout the UK – an important input used by local government and regulators to assess acceptable limits when granting environmental permits. This tool allows for precise estimates on future environmental impact to be generated, allowing regulators to find the optimum balance of environmental protection and enabling private sector development.

²⁴ United Nations Economic Commission for Europe (2004), Clearing the Air, 25 years of the Convention on Long-range Transboundary Air Pollution, http://www.unece.org/fileadmin/DAM/env/Irtap/ExecutiveBody/BOOKscreen.pdf (Accessed August 2015)

²⁵ United Nations Economic Commission for Europe (2004), Clearing the Air, 25 years of the Convention on Long-range Transboundary Air Pollution, http://www.unece.org/fileadmin/DAM/env/lrtap/ExecutiveBody/BOOKscreen.pdf (Accessed August 2015)

²³ Menz and Seip (2004), Acid rain in Europe and the United States: an update, Environmental Science & Policy 7, 253-265.

²⁶ Centre for Ecology and Hydrology – Staff Page: http://eic.nerc.ac.uk/staffwebpages/janehall.html (Accessed August 2015)

²⁷ Nitrogen in Europe (2013), European nitrogen assessment: sources, effects and policy perspectives

²⁸ CLEARFLO project website, http://www.clearflo.ac.uk (Accessed August 2015)

²⁹ APIS website, http://www.apis.ac.uk/ (Accessed August 2015)

NERC-funded researchers at Leeds University have developed the Master Chemical Mechanism (MCM), a set of complex equations used to model air pollutants. MCM has set international standards for the monitoring of ozone and is used by Defra as a reference mechanism to inform and evaluate policy. It has been described by the US Environmental Protection Agency as the 'gold standard' of chemical mechanisms, used to validate their regulatory model. This has led to improved air quality in the US and allowed the UK to lead international standards on air quality modelling.³⁰

The availability of new data and tools to mitigate air pollution can also be used by individuals and businesses to mitigate the negative impact of exposure to air pollutants. For example, NERC funding has supported the National Pollen and Aerobiology Research Unit's daily pollen forecasts used by the Met Office, GlaxoSmithKline and media outlets such as the Daily Telegraph. These forecasts help sufferers to manage their symptoms and avoid absences.

In each of the cases referred to in this section and section 4.2., the resulting reduction in emissions has benefitted the UK by reducing the negative health impacts associated with human exposure to pollutants, and in some cases reducing damage to ecosystems, wildlife and buildings.

4.2.3 Demonstrating UK international leadership in managing air pollution

Through its participation to the CLRTAP and the ENA, NERC science has enabled the UK government to obtain a stronger negotiating position in Europe and internationally NERC contributes to the development of new tools for managing the impacts of air pollution.

4.3 Beneficiaries and impact areas

NERC-funded research benefits the government and private sectors as well as members of the public, both in the UK and internationally. The decline of air pollutants that has stemmed from NERC-funded research has led to a reduction in the negative impacts on human health, crops, wildlife, habitats and the built environment. These impacts have generated cost savings to the public and private sectors. Details on how these impacts have been quantified (where possible) are provided in the following section.

4.4 Quantitative analysis

The primary quantitative benefit arising from NERC's funding in this area relates to the health benefits generated. These benefits stem from reduced emissions and concentrations of air pollutants, which have been achieved through policy implementation. Health benefits also accrue from the ability of people to avoid instances of excessively high concentrations through monitoring and forecasting activities. The following sections provide detail justifying the material contribution that NERC science made to help achieve these impacts (Section 4.4.1) and the methodology behind the quantification of these impacts (4.4.2-4.4.5).

It is important to note that for some of the quantifications, it was not possible to arrive at a precise 'net' benefit within the scope of this study. However, these costs are acknowledged and discussed below in section 4.4.6.

4.4.1 The materiality of NERC's impact

In the case of air pollution, the materiality of NERC's impact is based upon the scientific evidence it has provided that led to some of the most important policies for the reduction of air pollutants such as sulphur and nitrogen, amongst others. Unlike the stratospheric ozone impact assessment (Chapter 3), there is no secondary research which provides a clear counterfactual, which can be used to precisely estimate NERC's share of the benefits derived from the results of these policies.

With the above in mind, the approach taken below is to quantify the overall value of reduction in emissions through policy that has been developed based on NERC science. Specifically, evidence presented in section 4.2.1 demonstrates that the material scientific evidence that NERC provided to drive forward air pollution abatement

³⁰ University of Leeds (2014), REF 2014 Case Study: Development of abatement strategies and policies for air pollutant facilitated by the Master Chemical Mechanism.

policies began around 1990. As such, the reduction of emissions is valued beginning in 1990, when there is substantial evidence, which demonstrates NERC made a material contribution to achieving these benefits.

4.4.2 Valuation of emissions reductions since 1990

Using data from Defra, HM Treasury and Clean Air for Europe it has been possible to indicatively estimate the value of the reduction in emissions of five major pollutants, in terms of health impacts since 1990.³¹

Overall, the monetary saving (at 2015 prices) for the reduction in emissions since 1990 is estimated to be between £31bn and £82bn, given Defra measurements³² of emissions of five major pollutants.³³ This has been estimated using measurements of the marginal damage per tonne provided by the European Union as part of the Clean Air for Europe programme³⁴ and by HM Treasury³⁵ in the case of PM₁₀ for which a corresponding figure was not available. The calculations are outlined in the table below.

Pollutant	Sulphur dioxide	Volatile organic compounds	Nitrogen oxides	PM 10	Ammonia
Reduction in annual emissions ³⁶ (1990 to 2013) (tonnes)	3.3m (89%)	1.9m (71%)	1.9m (65%)	152k (55%)	73k (21%)
Marginal damage per tonne emission (£, 2015 prices) Lower limit	£5.6k	£0.9k	£3.3k	£25.5k	£14.4k
Marginal damage per tonne emission (£, 2015 prices) Upper limit	£16.1k	£2.7k	£8.5k	£37.0k	£42.3k
Estimated impact	£18bn-£53bn	£2bn-£5bn	£6bn-£16bn	£4bn-£5bn	£1bn-£3bn
Total			£31bn - £82bn		

Figure 3 Pollutant quantification

Source: Deloitte analysis based data from HM Treasury and the EU Clean Air for Europe Programme

For the above calculations, note that prices have been converted into GBP, using the 2000 EUR/GBP exchange rate of 0.6092 where required, and corrected to 2015 prices³⁷. Considering the value of reduction in sulphur dioxide alone (which was largely achieved based on NERC science), NERC's share of these total benefits could be in the region of 60%.³⁸

³¹ See notes accompanying each source for specific detail on the impacts addressed for each pollutant

³² Defra (2014), Statistical release: 18 December 2014: emissions of air pollutants in the UK, 1970 to 2013

³³ Sulphur dioxide, PM_{2.5}, Volatile organic compounds, Nitrogen oxides, PM₁₀ and Ammonia

³⁴ Clean Air for Europe (2005), Damages per tonne emission of PM_{2.5}, NH₃, SO₂, NO_x and VOCs from each EU25 Member State. These figures relate to the value (in terms of health impacts, crop damage, quality of life impacts and effects of resulting ozone depletion) of a reduction in emissions based on a unit price per tonne. Note, this publication does not provide an estimate for the marginal cost per tonne of PM₁₀. Also note that although the paper states values of emissions in 2000 prices, which have been adjusted to 2015 prices for this study.

 $^{^{35}}$ HM Treasury (2013), Valuing impacts on air quality: Supplementary green book guidance. Note that Clean Air for Europe did not provide a figure for PM₁₀ and so the figure provided in the supplementary green book guidance has been used. This valuation includes health impacts (both in terms of deaths and sickness) and the impact of building soiling

³⁶ Defra (2014), STATISTICAL RELEASE: 18 DECEMBER 2014: EMISSIONS OF AIR POLLUTANTS IN THE UK, 1970 TO 2013

³⁷ Clean Air for Europe (2005), Methodology for the cost benefit of CAFE – Volume 1: Overview of Methodology

³⁸ NERC Calculation

Data limitations have meant that it has not been possible to arrive at a net figure for the benefits of emissions reductions across all pollutants. It is, however, possible to indicatively estimate the net impact of the reduction in sulphur dioxide and nitrous oxides between 1990 and 2000, given that estimates of the abatement costs borne by industry are available.

A speech by Margaret Thatcher in 1990³⁹ stated that retro-fitting power generation facilities and ensuring new plants also met emissions guidelines related to these pollutants would cost industry £6bn at 1990 prices over the next ten years (the period 1990 to 2000). Assuming that this estimate is expressed at 1990 prices, it would equate to £11.5bn today. Over the corresponding time period emissions of sulphur dioxide and nitrogen oxides reduced by 2.5m tonnes and 1.1m tonnes respectively according to Defra's figures. At the marginal damages estimated above, the negative impact of this quantity of each pollutant ranges between £13.7bn and £32.9bn for sulphur dioxide and £3.6bn and £7.6bn for nitrous oxides, or between £17.3bn and £40.5bn in total (all expressed at 2015 prices). Allowing for the £11.5bn abatement costs, this suggests a net benefit of between £5.8bn and £29.0bn at 2015 prices.

4.4.3 Hay fever forecasting

Hay fever imposes negative costs on both the sufferers who face reduced life quality and the economy, by causing employees to be absent from work. This has been quantified based on the estimate that 4m days of absence from work result from hay fever in the UK⁴⁰ and the fact that the HSE estimates the value of avoiding one day's absence to be approximately £240⁴¹ at 2015 prices. Overall, this suggests that the impact on the economy from 4m annual absences due to hay fever is approximately £970m p.a.

4.4.4 Impact of PM_{2.5} pollution on UK life expectancy

While savings have been achieved via emissions reductions across a number of pollutants, concentrations of pollutants continue to have a negative impact across the UK. The magnitude of the negative health impacts of particulate air pollution in the UK have been quantified by Defra.⁴² As of 2008, Defra estimated that the health impacts of current levels of fine particulate pollution (PM_{2.5}) created through human activity resulted in an average reduction in life expectancy in the UK of approximately 6 months. Using a methodology which assigns a value to life years lost, the reduction in quality of life years and the cost of hospital admissions⁴³ Defra arrived at a value for the impact of £20.0bn annually when expressed at 2015 prices.

4.4.5 Nitrogen

Nitrogen continues to have an impact despite the reductions in emissions that have been achieved. An evaluation of the environmental effects of nitrogen pollution in Europe places a value on the negative health impact of nitrogen air pollution only slightly lower than that which Defra assigns to all PM_{2.5}⁴⁴ emissions. The European Nitrogen Assessment (ENA) estimated total annual health impacts of nitrogen emissions to be between €70bn and €320bn across the then 27 member states of the EU (of which 60% was attributable to the negative health impacts and air pollution). The ENA estimate is based on year 2000 emissions and using prices derived from the negative impacts per kg of emission of different forms of nitrogen.⁴⁵ Assigning the UK a gross domestic product (GDP) weighted share (according to IMF figures the UK accounted for 14.1% of the GDP of the 27 countries in the EU in 2013⁴⁶)

³⁹ Speech by Margaret Thatcher at the Royal Society marking the end of the Surface Water Acidification Programme, available online at *http://www.margaretthatcher.org/document/108046*

⁴⁰ NPARU website, http://www.worcester.ac.uk/discover/developing-pollen-forecast-vital-tool-prevention-treatment-hay-fever.html (Accessed August 2015)

⁴¹ HSE (2015), http://www.hse.gov.uk/risk/theory/alarpcheck.htm (Accessed August 2015). The HSE values one day's absence in the same way that it values a life. Each day of absence incurs productivity and health costs which you would pay up to their total impact to prevent. So the value of preventing a day's absence is the mirror of the cost to the economy of a day's absence.

⁴² Defra (2010), Valuing the overall impacts of air pollution

⁴³ The methodology is outlined in more detail in: Defra (2007), An economic analysis to inform the air quality strategy: Updated third report of the interdepartmental group on costs and benefits

⁴⁴ Nitrogen exists in multiple forms in the environment, including nitrates which fall under the PM_{2.5} classification

⁴⁵ Nitrogen in Europe (2013), European nitrogen assessment: sources, effects and policy perspectives

⁴⁶ IMF (2015), World economic outlook database, (Accessed August 2015)

and using the average EUR/GBP exchange rate for 2013 of 1.1796 suggests that Nitrogen pollution in the UK imposes a cost to human health of £14.6bn annually at 2015 prices at the mid-point of the range of estimates.⁴⁷

4.4.6 Assessment of costs

NERC estimates that its spending on air pollution related research is £3m annually. To give a clearer idea of the extent of this investment, Defra's spending on air pollution evidence is estimated to be £6m annually.⁴⁸ Drawing on the analysis undertaken in section 4.4.2, a speech by Margaret Thatcher in 1990 stated that retro-fitting power generation facilities and ensuring new plants also met emissions guidelines related to sulphur and nitrous oxide pollutants would cost industry £6bn at 1990 prices over the next ten years. Assuming that this estimate is expressed at 1990 prices, it would equate to £11.5bn today. When applied to the value of reduction of pollutants over that time period, it yields a net benefit of between £5.8bn and £29.0bn at 2015 prices.

4.5 Qualitative analysis

In addition to the quantification of the impact of air pollution, which largely focusses on health impacts on humans, there are a number of qualitative impacts which also result from NERC-funded research.

- Improvement and future protection of natural habitats, wildlife and quality of the natural environment: air pollution imposes societal costs by damaging natural habitats, however this impact cannot be quantified within the scope of this study. NERC-funded projects such as APIS act to minimise these effects by limiting emissions to a point where the environmental damage is minimised, while also avoiding overly restrictive regulation on the private sector which would hinder beneficial economic activity.
- Improvement in quality of life: Air pollution can generate haze and smog, which can reduce people's enjoyment of the natural environment as well as cause issues for some forms of transport (e.g. aviation and shipping). The burden placed on individuals and the private sector by these effects have been averted through reductions in pollutants resulting from NERC research and it's monitoring projects.
- Reduced damage to the built environment: Some pollutants, such as sulphur dioxide, also contribute to damages to buildings (in the case of sulphur dioxide this occurs through the acidification of water and acid rain). Such damages impose clean-up and defensive costs which must be borne by the public and private sectors. NERC-funded research which has supported policies such as CLRTAP, which reduced emissions of sulphur dioxide 92% over the last 35 years, contribute to the avoidance of these costs.

⁴⁷ This figure also includes the potential negative effect of water based nitrogen in human health, though this is estimated to be substantially smaller than the impact of airborne nitrogen pollution, and assumed to be 0 in the low impact scenario

⁴⁸ Based on 2011 figures, which show that Defra commits 5% of its total evidence spend to air quality, it can be estimated that Defra's spend on air quality evidence in 2014 amounts to approximately £6.3 million

5 Energy generation and resource extraction

Sustainable energy generation and resource extraction - NERC enables new industries and efficient regulation

Sustainable energy generation and resource extraction covers a number of industries which not only make an important contribution to the UK economy in terms of jobs, exports and earning, but also help support the UK's environmental sustainability.

The impact of NERC funding on research across the sector has played a prominent role in supporting the growth and viability of the sector. This funding, which amounts to £6.6m annually, has included research across a variety of sectors including:



This results in potentially cheaper energy for consumers that is generally safely and in a way that minimises environmental impacts and damage to public health.

5.1 Overview

NERC-funded research relating to energy generation and resource extraction spans across multiple sectors, ranging from wind energy, nuclear energy, shale gas, oil and gas and carbon capture and storage (CCS). The private sector plays a large role in investing in the growth of these sectors. NERC research has further enabled the development of these sectors through knowledge and technology that:

- Enables new industries and crowds-in private investment;⁴⁹
- Develops new technology and stimulates competition by lowering barriers to entry;
- Enables more efficient public sector regulation of sectors of the energy industry.

Ultimately, NERC's input across these three impact areas results in cheaper energy for consumers that is generated more safely and in a way that minimises the negative environmental impacts and damage to public health.

5.2 NERC inputs and outputs

NERC funding (inputs) has supported a number of research projects across all the energy industries considered in this study. Over the last 4 years, average NERC research funding for these sectors has been:⁵⁰

⁴⁹ Public sector investment into research and development (R&D) can have a positive, negative or no effect on private sector investment into R&D. Crowding-in refers to the positive effect, when public sector investment leads to additional levels of private sector investment. Crowding-in can occur for a variety of reasons; for example, public investment in R&D can allow for cost-sharing with the private sector for an investment for which there is not enough private sector demand to fund completely.

⁵⁰ NERC (2015), Energy related research grant statistics

Figure 4 NERC funding in energy sector

Energy sector	Annual NERC funding
Wind energy	£600,000
Nuclear energy	£1,700,000
Unconventional energy (including shale)	£800,000
Conventional oil and gas	£1,600,000
Carbon capture and storage	£1,900,000
Total	£6,600,000

Source: NERC

Supported through this funding, NERC's research centres the British Geological Survey (BGS) and National Oceanography Centre (NOC) have played a significant role in supporting certain sectors in the energy industry, such as nuclear energy, shale gas and oil and gas. Details on these contributions are provided in the following sections below.

The outputs that have been generated through this research funding vary across each sector. As such, the remainder of this section outlines the outputs of NERC research by sector. The impacts stemming from these outputs and the impact quantification are discussed in sections 5.3 and 5.4, respectively.

5.2.1 Wind energy

NERC-funded research has enabled additional wind energy capacity to enter the planning process in Eskdalemuir, Scotland by showing that it did not pose a seismic risk to nearby MoD installations. In addition, NERC has supported more efficient regulation of the industry and sped up the planning process for windfarms. This has been achieved through NOC demonstrating that offshore windfarms do not contribute significantly to coastal erosion and through supporting the development of a carbon calculating tool which allows planners to demonstrate sites environmental feasibility more effectively.

5.2.2 Nuclear energy

BGS's expertise supports the UK decommissioning industry via its understanding of geodisposal, which it exports globally via commercial research. Similarly, CEH radioecology expertise has informed numerous foreign governments and agencies following incidents and also permits more efficient regulation in the UK itself. For example, it informed the post-Chernobyl monitoring system, where it was able to reduce costs to the UK government by demonstrating that payments to farmers were no longer required.

5.2.3 Shale gas

BGS and university researchers have been critical to the safe development of the shale gas industry. Research at Keele University was able to demonstrate that shale extraction does not present significant seismic risks to nearby areas and research at Durham University has also helped to address concerns related to the risks posed to water supplies of the chemicals used in the extraction process. These findings have provided strong evidence to support the future development of the shale gas industry in the midst of opposition by providing a clearer understanding of the potential negative effects and how they can be avoided. Work by BGS to measure a national groundwater baseline will also support the regulation of the shale industry going forward by helping to identify any negative impacts to water supplies.

The National Geological Repository, a NERC/DECC funded store of over 20,000 drill samples, has also lowered barriers to entry in both the shale gas and in the on- and off-shore traditional oil and gas industries. It achieves this by providing geological data for firms wishing to explore a particular area without undertaking to drill a test-well, which can cost millions of pounds and deter smaller entrants with less resources than established firms in the industry.

5.2.4 Oil and gas

NERC-funded technologies have benefitted the oil and gas sector by improving the accuracy with which reserves can be identified under the ocean floor and improving the ability to determine reservoir content before drilling. These technologies, in addition to interpolated in-field referencing technology developed by BGS, which reduces the cost of drilling and the risk of accidents, have been widely adopted and act to reduce costs to the industry.

5.2.5 Carbon capture and storage

NERC research has demonstrated the technical and environmental viability of carbon capture and storage technologies and provided evidence which shows that it can be a viable greenhouse gas mitigation option. While the technology has yet to be widely adopted, investments have been announced, and it could offer the UK the ability to significantly reduce the cost of compliance with its 2050 emissions targets.

5.3 Beneficiaries and impact areas

The five energy sectors and case studies included in this analysis illustrate how the private sector is a significant beneficiary of NERC-funded science in this thematic area. As outlined above, NERC research outputs have led to three types of impacts which benefit private sector activities of these sectors:

- Enabling new industries and crowding-in private investment;
- Developing new technology and stimulating competition by lowering barriers to entry;
- Enabling more efficient public sector regulation of sectors of the energy industry.

Ultimately, the UK public is the main beneficiary of NERC-funded research, although this impact derives from intermediate outputs set out above, which benefit policymakers and firms within the energy industry. Wider society ultimately benefits from cheaper and more sustainable energy that is generated in a way that minimises negative environmental impacts and damage to public health.

5.4 Quantitative analysis

This section provides the materiality considerations around NERC's impact (5.4.1) and the detailed methodology on the impact quantifications of each of the energy sectors considered as part of this study (5.4.2-5.4.6).

5.4.1 The materiality of NERC's impact

The purpose of considering the materiality of NERC's impact is to demonstrate that the benefits stemming from its research would not have occurred in the absence of NERC research. Similar to air pollution, there is no secondary research that has defined and quantified the counterfactual for the impact areas in energy sectors where NERC research has contributed. As such, this section highlights several reasons why the impacts achieved would not have been so great (or would be less likely to have happened) without NERC's contribution.

Firstly, NERC-funded research has unlocked additional private sector investment, which otherwise may not have come forward, meaning less investment in and development of particular energy sectors. When public sector funding on R&D (such as NERC-funded research) has a positive effect on private sector investment in R&D, it is referred to as crowding-in. An empirical study recently conducted for the Department for Business, Innovation and Skills found that a 1% increase in public expenditure on R&D will lead to between a 0.48% and 0.68% increase in private expenditure on R&D.⁵¹

A number of case studies of NERC research in the energy sector shows evidence of crowding-in. For example, NERC's monitoring of the Sleipner site in the North Sea has been central to providing the environmental and technical feasibility of CCS. This research reduces the risk of private sector investment in R&D to commercialise

⁵¹ Economic Insight (2015), What is the relationship between public and private investment in science, research and innovation? A report commissioned by the Department for Business Innovation and Skills:

 $https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/438763/bis-15-340-relationship-between-public-and-private-investment-in-R-D.pdf$

this technology, since the technology has already been proven environmentally and technically sound. It is unlikely that a private sector firm or researcher would have had the resources (both financial and in terms of infrastructure) to invest time and money to this research given the high risks associated with it generating any financial returns.

Secondly, even if other organisations (such as universities) were to provide similar research in the absence of NERC, it is unlikely that it would be of the same depth and breadth as that which NERC Research Centres are capable of producing. Not only do NERC's Research Centres bring together world leading scientists and foster expertise and excellence, but the long-term repositories of data that the Centres can draw on is unprecedented compared to other UK research organisations and universities. For example, BGS operates the largest drill core facility in the UK, with a repository of over 23,000 UK drill-cores available for firms and other researchers to analyse. Analysing drill cores can save private sector costly unnecessary drilling in the oil and gas and shale industries.

5.4.2 Wind energy

Sector GVA: The estimate provided for the size of the wind sector's GVA contribution to the UK economy of £920m is based on an estimate provided for 2014 by RenewableUK⁵², adjusted to 2015 prices.

Eskdalemuir: The economic impact of the capacity in Eskdalemuir, Scotland, enabled by NERC scientists at Keele University is estimated to be £1.2bn over 25 years, or £50m annually. This is an indicative estimate which assumes that all capacity enters development this year, and is intended to highlight the magnitude of the opportunity in GVA terms.

This figure is arrived at using a number of data sources. Firstly, the estimated capacity of 1GW has been taken from a speech by the Scottish Energy Minister, Fergus Ewing, following the publication of the findings of the Eskdalemuir Working Group in 2014.⁵³ To estimate the potential GVA impact of the development over its lifetime, project expenditure figures from RenewableUK have been used. These included the values for the per MW expenditure and the percentage of this spend which remains in the UK. GVA ratios for the three stages of the wind farm process (development, construction and operation and maintenance) on a per MW basis are applied to total expenditure to arrive at the GVA supported through the development.⁵⁴ These ratios have been applied to 1GW capacity over a 25 year period, assuming 2 years development, 3 years construction and 20 years operations and maintenance from 2015, applying a 3.5% discount rate to GVA in future years. The calculation is outlined in the table below.

⁵² RenewableUK (2015), Onshore wind economic impacts 2014

⁵³ RenewableUK (2014), Press release: 'RenewableUK hails new study which unlocks over 1,000 megawatts of wind energy'

⁵⁴ RenewableUK (2015), Onshore wind economic impacts 2014

Figure 5 Wind energy modelling assumptions

Years	1-2 (2 years)	3-5 (3 years)	6-25 (20 years)		
Phase	Development	Construction	Operation		
Annual expenditure per MW (2014 prices)	£150,216 £1,318,875		£59,867		
Annual expenditure per MW (2015 prices – CPI adjusted)	£152,469	£1,338,658	£60,765		
MW capacity	1,000				
UK share of revenues	98%	47%	87%		
GVA/Turnover Ratio	0.666	0.432	0.430		
GVA impact (annual)	£99.5m	£271.8m	£22.7m		
Total (includes discounting)	£195.5m	£195.5m £733.1m			
Total across all years	£1.2bn				

Source: Deloitte analysis and data from Renewable UK

Coastal erosion monitoring savings: NOC estimates that a public sector saving of £3.6m was achieved in coastal erosion monitoring due to its findings that offshore windfarms do not contribute to the issue. This has been informed by the NERC documents shared as part of this assessment.⁵⁵

5.4.3 Nuclear energy

BGS commercial income: BGS earns £1m in commercial income annually from its research into the diffusion of radioactive gasses in rocks. The figure is based on BGS's own estimate.⁵⁶

Post-Chernobyl monitoring payments: Research into the radiological effects of nuclear accidents allowed CEH to provide evidence to cease government payments to farmers as part of the Post-Chernobyl monitoring programme amounting to £655k. This figure is based on the assessment of CEH⁵⁷ and NERC's contribution has been referenced in a 2012 report by the Food Standards Agency.⁵⁸

5.4.4 Shale gas

Bowland basin sizing: The estimated revenues of £136bn from the Bowland Basin shale reservoir are based on the assessment of Cuadrilla⁵⁹, a firm responsible for some of the first shale extraction in the UK. Given that the value of prospects is more dependent on current commodity prices than inflation, this figure has not been readjusted to the 2015 reference year in line with most of the figures in this report.

Test well costing: The indicative cost of a shale test well is estimated to be £12m based on figures published in a House of Commons Library Briefing.⁶⁰ Given that the estimate was made in 2011, it has been corrected to reflect 2015 prices.

⁵⁵ NERC (2013), NOC show wind farms' impacts on coastal erosion is not a concern

⁵⁶ BGS (2013), Radioactive waste – BGS case study

⁵⁷ NERC (2014), CEH case study: Leading international initiatives to improve assessment of the exposure of humans and wildlife to ionising radiation

⁵⁸ FSA (2012), The removal of post-Chernobyl sheep controls

⁵⁹ Cuadrilla (2013), Statement reported in BBC news 1st February 2013, http://www.bbc.co.uk/news/uk-england-lancashire-21296679 (Accessed August 2015)

⁶⁰ HoC Library (2015), Briefing paper: shale gas and fracking

National Geological Repository (NGR) valuation: The valuation of the benefits derived from the NGR is estimated by multiplying Oil and Gas sector GVA by the proportion of spending on NGR collection and analysis relative to overall industry R&D spending. This provides an indicative contribution of NGR supported activities, resting on the assumption that Oil and Gas GVA is a function of the current R&D activities supporting it. To reduce the effects of volatility in sectoral GVA, and to allow for the fact that R&D can generate benefits in years other than those in which it is carried out, a 6 year average has been taken between 2007 and 2012 (the years in which all of the required data is available). Across the six years, the average share attributable to the NGR was estimated to be £388.2m. The steps in this calculation are outlined in the following table.

Figure 6 Shale gas modelling assumptions

Year	2007	2008	2009	2010	2011	2012	
Part 1 – expenditure at NGR							
Lab days spend analysing NGR offshore and onshore collections by commercial users ⁶¹	285	190	322	221	356	340	
% time spend looking for data by O&G technical staff ⁶²	30%						
Total time (days) spent collecting and analysing NGR offshore and onshore collections by commercial users	950	633	1073	737	1187	1133	
Cost to O&G company of a contractor engaged in using NGR data ⁶³	£1,500						
Estimated expenditure on collection and analysis of NGR offshore and onshore data by commercial users	£1.4m	£1.0m	£1.6m	£1.1m	£1.8m	£1.7m	
Part 2 – total industry R&D spending							
Expenditure on R&D performed by UK extractive industries ⁶⁴ (corrected to 2015 prices using CPI)	£102.6m	£110.1m	£165.3m	£175.7m	£218.2m	£220.5m	
Part 3 – NGR expenditure / total industry GVA							
Proportion of spending attributable to collection and analysis of NGR data relative to total industry expenditure on R&D	1.4%	0.9%	1.0%	0.6%	0.8%	0.8%	
Part 4 – O&G sector GVA							
Oil and Gas sector GVA ⁶⁵ (corrected to 2015 prices using CPI)	£50.7bn	£48.4bn	£44.5bn	£41.7bn	£34.7bn	£29.9bn	
Part 5 – NGR expenditure share of O&G GVA							
Share of O&G GVA attributable to NGR resources	£703.2m	£417.1m	£433.3m	£262.3m	£282.9m	£230.5m	
Average share of O&G GVA attributable to NGR resources	£388.2m						

- ⁶³ This is based on an assumed £1,000 rate with 50% overheads
- ⁶⁴ ONS (2014), Business Enterprise Research and Development, 2013
- 65 BIS (2015), Industrial strategy

⁶¹ NERC (2013), geological Repository

 $^{^{\}rm 62}$ CDA (2011), The business value case for data management - a study

5.4.5 Oil and gas

Interpolated in-field referencing (IIFR) drill-time saving: To indicate the magnitude of the savings facilitated by BGS drilling technology, the cost of a day's deep-water drilling is calculated to be £330k. This is based on contractor rates from Rigzone⁶⁶, an industry website, for deep water drilling of c. \$500k per day. These have been presented in GBP for comparability with the other figures in this report based on the average USD exchange rate for 2015 to the end of August of 1.5319 \$/£.

5.4.6 Carbon capture and storage

Reduction in cost to meet UK climate change targets 2050: The reduction in the costs associated with meeting the UK's climate change targets are from estimates by the Carbon Capture and Storage Association and the Trade Union Congress of between £30bn and £40bn.⁶⁷ Given that the estimate was made in 2014, it has been corrected to reflect 2015 prices.

5.4.7 Assessment of costs

Overall, NERC's funding for research across the sectors identified amounts to £6.6m p.a.

5.5 Qualitative analysis

NERC-funded research has supported the development of new industries and economic activity, while also contributing to cost savings to consumers and the public sector. In addition, NERC research also generates qualitative benefits such as increased safety via improved regulation. While these impacts cannot be quantified within the scope of this study, they still demonstrate that NERC has made a demonstrable positive impact.

For example, NERC-funded research into the risks (relating to seismic tremors and contamination of groundwater) posed by shale gas extraction has informed regulation to protect public health. BGS's work to develop a national groundwater baseline will enable regulators to accurately measure the impact of extraction activities, and protect the public from any negative consequences. Similarly, expertise in radioecology and geodisposal developed by NERC Research Centres informs responses to nuclear incidents, protecting the public from negative health impacts. These activities are likely to deliver significant health benefits to both the UK public and internationally through more informed regulation.

⁶⁶ Rigzone website, Offshore rig day rates, http://www.rigzone.com/data/dayrates/ (Accessed August 2015)

⁶⁷ CCSA & TUC (2014), The economic benefits of carbon capture and storage in the UK

6 Risk identification and analysis

Risk identification and analysis - NERC research saves lives and puts resources to more productive uses

Environmental events, such as extreme seasonal temperatures, flooding and volcanic eruptions, can negatively impact human life, infrastructure and wildlife. While these natural hazards are unavoidable, their negative effects can be minimised by better understanding of the precise nature of risks involved.

NERC-funded scientists identify and analyse environmental risks, providing important information which allows the public and private sector to better prepare for, mitigate and manage any subsequent impacts. Over the last five years, NERC has invested an average of \pounds 12.8m p.a. into research on natural environmental hazards; this has led to:



6.1 Overview

NERC funding of science helps to develop a clearer understanding of environmental risk which can be used by both the public and private sectors to minimise negative effects through understanding the precise nature of the uncertainty involved. NERC research has been used to:

- More accurately forecast seasonal weather patterns, minimising winter deaths and economic disruption;
- Minimise the disruption of aviation by volcanic ash, generating cost savings for airlines and time saved for passengers;
- Inform early warning and mitigation efforts for flooding, saving lives and allowing time and money to be used more productively;
- Understand and minimise risks to animal habitats, protecting wildlife while allowing beneficial economic activity;
- Provide the evidence to inform climate change policy, protecting quality of life and the environment;
- Provide early warning of global extreme weather events, saving lives by enabling evacuations.

6.2 NERC inputs and outputs

NERC funding supports numerous outputs that help individuals, as well as the public and private sectors, to better manage risk and uncertainty. These include improvements in seasonal forecasting, research into volcanic ash dispersal, flood modelling, environmental impact modelling, climate change forecasting and international forecasting of extreme weather events.

Over the period 2007/8 – 2011/12, NERC invested an average of £12.8m p.a. on research, knowledge exchange and training focused on resilience to natural environmental hazards.

6.2.1 Seasonal forecasting

NERC-funded research into seasonal forecasting has resulted in a number of outputs. Research at the University of Birmingham developed route based forecasting (RBF) tools that enable local councils to implement snow and ice mitigation measures more effectively. NERC data also feeds into the Met Office's Seasonal Forecasts, enabling the public and private sectors to better prepare for atypically hot or cold weather. Finally, NERC-funded research into high speed winds, or string jets, have enabled the Met Office to provide warnings in its National Severe Weather Warning Service.

6.2.2 Volcanic ash dispersal

NERC-funded research is central to the understanding of the dispersal of volcanic ash and its effects on the aviation industry. Following the 2010 Eyjafjallajökull eruption in Iceland, flights throughout Europe were grounded over concerns of ash affecting the engines of planes. NERC research into the event supported the case for early reopening of the closed areas and for far less extensive closures during a second, similar eruption a year later.

6.2.3 Flood modelling

NERC scientists at both the CEH and NOC have developed expertise in modelling multiple sources of flooding which has increased the number of days in advance that flood warnings can be issued by the Met Office. Modelling efforts have also improved the mitigation of the impacts of flooding by informing better flood defences in vulnerable areas.

6.2.4 Environmental impact modelling

NERC-funded scientists have also developed natural resources monitoring and modelling tools which can inform environmental conservation policies while facilitating economic activity. For example, cod population modelling undertaken at the University of Strathclyde altered EU policy towards cod fishing in the North Sea.

6.2.5 Climate change modelling

A number of NERC-funded projects at the University of Reading, Durham, Leicester and the LSE have informed climate change measurement and forecasting, as well as policymakers' understanding of these forecasts. This research has provided scientific basis for reduction in greenhouse gas emissions needed to meet the UK government's target temperature increase under the UK Climate Change Act 2008 and has also been used by UK negotiators in the UN Framework Convention on Climate Change to which the UK is a signatory.

6.2.6 International extreme weather forecasting

In addition to modelling of UK weather, NERC-funded research has also improved forecasting of international extreme weather events, improving the ability for developing countries to respond to natural disasters. The NERC-funded Tropical Storm Risk (TSR) model, for example, has been used to inform evacuation plans. The model was central to the evacuation of one million people from coastal areas of Bangladesh during the Mahasen tropical storm in 2013.

6.3 Beneficiaries and impact areas

The outputs of NERC research help the public and private sectors better manage risk and uncertainty, helping to avoid negative outcomes or minimise their effects. The final outcomes resulting from NERC's funding includes public health benefits resulting from better mitigation efforts, private sector savings in damages from extreme weather and the enabling of beneficial economic activity to take place due to an increased understanding of the risks associated with it. The impact areas specific to each of the risk identification and analysis areas are detailed below.

6.3.1 Seasonal forecasting

NERC's funding into seasonal forecasting benefits both the public and private sectors, and reduces the costs and negative health impacts faced by individuals. Route Based Forecasting technology has enabled local governments to reduce the costs of gritting activities, generating public sector savings. Seasonal forecasting of cold spells also allows the Department for Health to implement its Cold Weather Plan, which helps to reduce excess winter deaths, of which there were 31,000 in 2013, many of which could be avoided with better preparation. Finally, forecasting of winds and storms by the Met Office, supported by NERC-funded research and data, helps to minimise the health risks to the public, and enable industries to plan more effectively to avoid disruption, facilitating cost savings.

6.3.2 Volcanic ash dispersal

Research undertaken by the CEH and other NERC-funded scientists into the dispersal of volcanic ash has benefitted both the aviation industry, as well as the public and private sector activity dependent on the ability to travel. Through its contribution to the lifting of flights bans since 2011, NERC has delivered cost savings to the aviation industry in the order of £290m per day a ban is avoided. In addition, there is likely to have been a saving to other industries affected as well as to the public who face reduced disruption to travel plans.

6.3.3 Flood warning

Over five million properties in the UK are at risk of river, coastal or surface water flooding. NERC-funded research into modelling supports both forecasting and modelling of mitigation attempts. These collectively act to reduce the impact of flooding on public health as well as limit property damage through enabling preventative measures to be taken in advance which limit the damage caused by flooding. For example, the Met Office estimates that up 10% of the damage caused by flooding can be avoided through early warnings provided by NERC models such as the grid-to-grid model developed by the CEH. On an average year this could prevent up to £127m in damages to homes, buildings, farmland and infrastructure.

6.3.4 Environmental impact modelling

By developing a more informed view of the impacts of economic activity on the natural environment, NERC-funded research allows beneficial economic activities to take place. An example of this is the work of NERC-funded scientists at Bournemouth University that developed a computer programme to model the risk of human activities that negatively affect birds. This has been applied to regulate 881km² of England's coastal and brackish water classified as shellfish surface water (SFW) by DEFRA. Not only is the natural habitat's protection ensured, but beneficial economic activity is able to continue since its consequences can be measured and monitored.

6.3.5 Climate change modelling

Climate change models which influence policymakers are vital to ensuring that the resulting policies are as efficient as possible, reducing the negative impacts of climate change on human health, crops and the environment while also avoiding excessive limits on economic activity. NERC-funded research provided the scientific basis for the reduction in greenhouse gas emissions needed to meet the UK government's target temperature increase under the UK Climate Change Act 2008. The UK Climate Change Act has been estimated by DECC to deliver £784.4bn (from health benefits, cost savings to agriculture and reduced property damage) between 2008 and 2050, highlighting the scale of the impacts which NERC funding contributes towards.

6.3.6 International extreme weather forecasting

The beneficiaries of NERC funding into international forecasting include citizens of developing countries who suffer disproportionately from the effects of extreme weather. The NERC-funded TSR model, for example, gives national authorities and NGO's advanced warning to coordinate evacuations. TSR forecasts were central to the evacuation of one million people from coastal areas of Bangladesh before the Mahasen tropical storm in 2013, which the UN determined to have saved 'many thousands of lives'⁶⁸

6.4 Quantitative analysis

This section provides the materiality considerations around NERC's impact (6.4.1) and the detailed methodology on the impact quantifications of each of the areas relating to risk identification and analysis, considered as part of this study (6.4.2-6.4.6).

⁶⁸ UN News centre website, http://www.un.org/apps/news/story.asp?NewsID=44946#.VdSZ3pjJBOK (Accessed August 2015)

6.4.1 The materiality of NERC's impact

Similar to the areas of air pollution and energy, there is no clear counterfactual scenario that has been studied to isolate the impact of NERC-funded research in the area of risk analysis. While it is clear to see how NERC-funded research directly led to positive impacts in each of the case studies presented below, it is difficult to gauge how much of this impact is additional to NERC. In the absence of such information, the materiality of NERC's contribution is developed through the narrative, which directly link's NERC research outputs to the end user and positive impacts created.

6.4.2 Seasonal forecasting

Seasonal cold weather: The impact of severe cold during the winter of 2010 was estimated by the ONS to be 0.5% GVA⁶⁹, or £1.8bn at to 2015 prices.

Route based forecasting: The use of Route Based Forecasting in the Highlands has been found to save 8%⁷⁰ of the Council's winter budget in 2013, amounting to £410k at 2015 prices.

Cold weather health costs to NHS England: The health costs associated with cold weather in England are estimated by Age UK to be £1.5bn⁷¹ at 2015 prices.

Impacts of high speed wind: The Met Office have estimated savings of its severe wind warning system⁷² to be £43m to the construction industry, £51m to the emergency services, £120m through improved aircraft routing and £5m in reduced flight delays at 2015 prices.

6.4.3 Volcanic ash dispersal

Savings to the aviation industry: The International Air Transport Association (IATA) estimated that the daily losses resulting from the closure of European airspace following the 2010 Eyjafjallajökull volcanic eruption in Iceland to be £300m⁷³ per day at 2015 prices given average 2010 exchange rates (\$400m USD at 2010 prices, converted to pounds at the 2010 average exchange rate of 1.5459 and corrected at CPI to reflect 2015 prices).

Following the 2010 eruption, NERC funding supported research to better understand the dynamics of ash dispersal as well as its impact on flights. A better understanding of the risks was credited by the European Commission as being part of the reason that flight bans following a similar eruption to that of 2010 one year later resulted in far less extensive flight cancellations.⁷⁴

Following the 2011 eruption, a total of 900 flights were cancelled, compared to 42,600 in the same period in 2010. Overall, this suggests 98% fewer flights were cancelled daily, amounting to a saving of £290m for each day that NERC-funded research into the risks to aviation was able to keep airspace open. This saving includes only the impact on the aviation industry, and there is likely to have been further benefits to other industries as well as the public from limiting flight disruption.

It is acknowledged that the nature of the two volcanos is different, due in part to the different weather conditions, which does not make them a perfectly accurate comparison. Nevertheless, the European Commission stated that the situation for the second volcanic eruption was very different 'to a much greater extent due to the more precise risk assessment procedures that have been put in place in Europe.' While the two are not a perfect comparison,

⁶⁹ HoC Transport Committee (2011), Keeping the UK moving: the impact on transport of the winter weather in December 2010. GVA stated in 2015 prices

⁷⁰ REF case study (2014), Keeping transport systems running in winter: the contribution of Route-Based Weather Forecasting

⁷¹ Age UK (2009), The Cost of Cold

⁷² Met Office (2007), Public Weather Service's contribution to the UK economy

⁷³ IATA (2010), Volcano crisis costs airlines \$1.7 billion in revenue

⁷⁴ European Commission (2011), Memo/11/346

with support from the European Commission acknowledgement, it is fair to assume that the impact measurement of NERC in reducing the number of days of disruption is valid.⁷⁵

6.4.4 Flood warning

Damage reduction from early warning capabilities: The reduction in damages from flood early warning systems is estimated to be between £76m and £127m p.a. based on an estimate by the Met Office that 6-10% of flood damage can be avoided through the issuance of early warnings⁷⁶ and an estimate by the UK Environment Agency that the average annual impact of flooding and coastal erosion in terms of damage to homes, businesses, farmland and infrastructure amounts to £1.27bn at 2015 prices.⁷⁷

Rydale flood defence net benefits: The £230k net benefit from the Rydale flood defence pilot project, informed by a NERC-funded computer model developed at Durham University is taken from a Defra report into the schemes impact⁷⁸, corrected to reflect 2015 prices.

6.4.5 Environmental impact modelling

Shellfisheries: Scientists at Bournemouth University estimate that the use of a computer program developed through NERC funding which models the risk of human activities to coastal bird populations regulates shell fishing in an area which generates a turnover of between £9.6m and 20.1m p.a. at 2015 prices.⁷⁹

Cod fisheries: Modelling by Strathclyde University into cod populations in the North Sea has been estimated to have increased the UK's share of fishing revenues by £8.6m⁸⁰ at 2015 prices by influencing an EU decision to allow additional fishing to take place. This has been estimated using data within the REF case study, from the fact that the total additional revenue facilitated was £17m across the North Sea, of which 45% was attributable to the UK fishing industry, giving £7.7m in 2011, the year in which the estimate was made. This has been corrected to 2015 prices.

Salmon farming: NERC-funded software which models the impact of fish farming on sensitive habitats under Natura 2000 regulations has likely led to activity taking place that would otherwise be prohibited. The overall turnover of the Scottish salmon farming industry is £690m p.a.⁸¹ according to industry estimates (for 2013) expressed at 2015 prices.

6.4.6 Climate change modelling

Impact of UK Climate Change Act 2008: The net benefits of the Climate Change Act have been estimated by DECC as part of the policymaking process.⁸² These estimates express the net benefits in terms of health benefits, costs savings to agriculture and reduced property damage as £784.4bn between 2008 and 2050 at 2015 prices.

6.5 Qualitative analysis

Given available information it has not been possible to quantify the value of NERC-funded research into international extreme weather forecasting. This is partially as it is likely most valuable in developing countries where data is not as readily available. The NERC-funded TSR model, however, has been credited with saving 'many thousands of lives'⁸³ in just one instance of its use in 2013, suggesting that it's global impact is highly significant.

⁷⁵ European Commission (2011), Memo/11/346

⁷⁶ Public weather service value for money review (2015), Public weather service customer group secretariat

⁷⁷ Environment Agency (2014), Flood and coastal erosion risk management: long term investment scenarios

⁷⁸ Defra (2011), Slowing the flow at Pickering

⁷⁹ REF case studies (2014), Model helps balance coastal bird conservation and needs of society

⁸⁰ REF case studies (2014), Recovery of cod stocks in the North Sea achieved by a change in EU fisheries policy

⁸¹ Scottish salmon producers organisation, http://scottishsalmon.co.uk/good-news-for-rural-economies-set-to-continue-says-salmon-farming-body/ (Accessed August 2015)

⁸² DECC (2009), Climate Change Act 2008: Impact Assessment

⁸³ UN News centre website, http://www.un.org/apps/news/story.asp?NewsID=44946#.VdSZ3pjJBOK (Accessed August 2015)

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