Report No. **223**

epa Research
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

A Summary of the State of Knowledge on Climate Change Impacts for Ireland

Authors: Margaret Desmond, Phillip O'Brien and Frank McGovern

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

www.epa.ie

ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

Regulation: *We implement effective regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.*

Knowledge: *We provide high quality, targeted and timely environmental data, information and assessment to inform decision making at all levels.*

Advocacy: *We work with others to advocate for a clean, productive and well protected environment and for sustainable environmental behaviour.*

Our Responsibilities

Licensing

We regulate the following activities so that they do not endanger human health or harm the environment:

- waste facilities *(e.g. landfills, incinerators, waste transfer stations)*;
- large scale industrial activities (*e.g. pharmaceutical, cement manufacturing, power plants)*;
- intensive agriculture *(e.g. pigs, poultry)*;
- the contained use and controlled release of Genetically Modified Organisms *(GMOs)*;
- sources of ionising radiation *(e.g. x-ray and radiotherapy equipment, industrial sources)*;
- large petrol storage facilities;
- waste water discharges;
- dumping at sea activities.

National Environmental Enforcement

- Conducting an annual programme of audits and inspections of EPA licensed facilities.
- Overseeing local authorities' environmental protection responsibilities.
- Supervising the supply of drinking water by public water suppliers.
- Working with local authorities and other agencies to tackle environmental crime by co-ordinating a national enforcement network, targeting offenders and overseeing remediation.
- Enforcing Regulations such as Waste Electrical and Electronic Equipment (WEEE), Restriction of Hazardous Substances (RoHS) and substances that deplete the ozone layer.
- Prosecuting those who flout environmental law and damage the environment.

Water Management

- Monitoring and reporting on the quality of rivers, lakes, transitional and coastal waters of Ireland and groundwaters; measuring water levels and river flows.
- National coordination and oversight of the Water Framework Directive.
- Monitoring and reporting on Bathing Water Quality.

Monitoring, Analysing and Reporting on the Environment

- Monitoring air quality and implementing the EU Clean Air for Europe (CAFÉ) Directive.
- Independent reporting to inform decision making by national and local government *(e.g. periodic reporting on the State of Ireland's Environment and Indicator Reports)*.

Regulating Ireland's Greenhouse Gas Emissions

- Preparing Ireland's greenhouse gas inventories and projections.
- Implementing the Emissions Trading Directive, for over 100 of the largest producers of carbon dioxide in Ireland.

Environmental Research and Development

- Funding environmental research to identify pressures, inform policy and provide solutions in the areas of climate, water and sustainability.

Strategic Environmental Assessment

- Assessing the impact of proposed plans and programmes on the Irish environment *(e.g. major development plans)*.

Radiological Protection

- Monitoring radiation levels, assessing exposure of people in Ireland to ionising radiation.
- Assisting in developing national plans for emergencies arising from nuclear accidents.
- Monitoring developments abroad relating to nuclear installations and radiological safety.
- Providing, or overseeing the provision of, specialist radiation protection services.

Guidance, Accessible Information and Education

- Providing advice and guidance to industry and the public on environmental and radiological protection topics.
- Providing timely and easily accessible environmental information to encourage public participation in environmental decision-making *(e.g. My Local Environment, Radon Maps)*.
- Advising Government on matters relating to radiological safety and emergency response.
- Developing a National Hazardous Waste Management Plan to prevent and manage hazardous waste.

Awareness Raising and Behavioural Change

- Generating greater environmental awareness and influencing positive behavioural change by supporting businesses, communities and householders to become more resource efficient.
- Promoting radon testing in homes and workplaces and encouraging remediation where necessary.

Management and structure of the EPA

The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:

- Office of Environmental Sustainability
- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA RESEARCH PROGRAMME 2014–2020

A Summary of the State of Knowledge on Climate Change Impacts for Ireland

Report 11 (2010–2016)

(2014-CCRP-FS.19)

EPA Research Report

Prepared for the Environmental Protection Agency

by

MaREI Centre, Environmental Research Institute, University College Cork

Authors:

Margaret Desmond, Phillip O'Brien and Frank McGovern

ENVIRONMENTAL PROTECTION AGENCY
An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
Email: info@epa.ie Website: www.epa.ie

ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2014–2020. The programme is financed by the Irish Government. It is administered on behalf of the Department of Communications, Climate Action and Environment by the EPA, which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to thank staff at Met Éireann, Maynooth University, the National University of Ireland Galway (NUIG), Trinity College Dublin, the Irish Centre for High End Computing (ICHEC), the MaREI Centre (Beaufort, UCC), the Office of Public Works (OPW), the Department of the Environment, Heritage and Local Government and the Department of Agriculture, Fisheries and Food. In particular, we thank Ray McGrath (Met Éireann, retired) for his reviews and for providing very useful comment and feedback throughout. Thanks are also due to colleagues in the EPA for additional comment and review. Finally, thanks go to Maria Jacob (intern with the EPA in 2015).

Cover images: Top left – climate observations, courtesy of Met Éireann, reproduced under a CC BY-SA 2.0 licence. Top right – climate change impact, courtesy of Iarnród Éireann (http://www.raiu.ie/download/pdf/structural_failure_of_a_platform_canopy_at_kent_station_.pdf). Bottom – "We need to talk about climate change", courtesy of Barry O'Dwyer, University College Cork.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA RESEARCH PROGRAMME 2014–2020

Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-84095-733-4 September 2017

Price: Free Online version

Project Authors

Dr Margaret Desmond
Senior Research Fellow (Climate change impacts and adaptation)
MaREI Centre
Environmental Research Institute
University College Cork
Cork
Ireland
Email: m.desmond@ucc.ie

Mr Phillip O'Brien
Scientific Officer Adaptation
Secretariat to Climate Change Advisory Council
EPA, Office of Climate, Licensing and Resource Use
McCumiskey House
Richview
Clonskeagh Road
Dublin 14
Ireland
Email: p.obrien@epa.ie

Dr Frank McGovern
Chief Climate Scientist
EPA, Office of Climate, Licensing and Resource Use
McCumiskey House
Richview
Clonskeagh Road
Dublin 14
Ireland
Email: f.mcgovern@epa.ie

Contents

List of Figures, Tables and Boxes

Figures

Tables

Boxes

Executive Summary

This report presents a summary of the state of knowledge on ongoing climate change and projected impacts for Ireland. It updates and enhances the information provided in the 2009 Summary of the State of Knowledge Report (Desmond *et al*., 2009). The information provided takes account of new data, analyses and knowledge that have been published since then.

The purpose of this report is to provide an accessible summary of the available information in a format that will be of use to policymakers, sectoral and local decision-makers and other stakeholders interested in or working on adaptation to climate change in Ireland. The national information is largely based on Environmental Protection Agency- (EPA) funded research and linked research funded by other national bodies, including Met Éireann, the Office of Public Works (OPW) and the Marine Institute, and research carried out by third-level institutes. The material in this report should be viewed within the wider context provided by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Reports (AR5) (2013a,b, 2014a,b). The development of this report has also been supported by the "Climate Ireland" information portal. It has further been shaped by the inputs of national experts through a series of stakeholder events held in 2015.

Warming of the global climate system is unequivocal and it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century (IPCC, 2013). Mitigation actions are being taken to limit climate change, most notably the 2015 Paris Agreement. However, many changes and their associated impacts are "locked-in" to the Earth's climate systems and past actions will drive changes for decades to come. There is now a clearer understanding of how the risks of climate change can be reduced and managed through mitigation and adaptation actions (IPCC, 2014).

The impacts of climate changes are evident on natural and human systems on all continents and across the oceans (IPCC, 2014). Observations show that Ireland's climate is also changing. The observed scale and rate of change is consistent with regional and global trends across the range of essential climate variables discussed in *The Status of Ireland's Climate, 2012* (Dwyer, 2012). These changes are projected to continue and increase over the coming decades (Gleeson *et al*., 2013). However, the climate of the North Atlantic and the regional impact of the melting of the Greenland ice sheet may cause unique climate change issues in this region (Rahmstorf, 2015).

Climate change means not only changes in the average climate such as temperature, but also changes in the frequency and intensity of extreme weather and climate events. It is recognised that extreme events, such as severe flooding, droughts and heat-/cold waves, can have important socio-economic consequences. Changes in their frequency and intensity are therefore of particular interest to policymakers and stakeholders (O'Sullivan *et al*., 2015; Nolan *et al*., 2013, 2015).

Observed and projected physical climate changes include:

- increase in average temperature (surface air temperature, sea surface temperature);
- changes in precipitation patterns;
- ongoing mean sea level rise;
- changes in the character of weather extremes such as storms, flooding, sea surges and flash floods.

In Ireland, climate change will have diverse and wide-ranging impacts on the environment, society, economic sectors and natural resources. These include managed and natural ecosystems, water resources, agriculture and food security, human health, and coastal infrastructures and zones (Coll and Sweeney, 2013).

Extreme weather events give rise to the most immediate and severe impacts for natural and managed systems (e.g. agriculture and forestry) as well as infrastructure and economic and societal disruption. Changes in the number or nature of extreme weather events are therefore of concern.

Climate change may offer some opportunities for sectors such as tourism and agriculture in the short to medium term (Sweeney *et al*., 2013).

Risks associated with a changing climate depend on the exposure and vulnerability of the affected system and its ability to absorb and adapt to such change. Adaptation has the potential to effectively manage and minimise adverse climate change impacts, but this potential or adaptive capacity differs between sectors and regions. Ultimately, there are constraints and limits to adaptation.

Addressing uncertainties is a key challenge for actions on adaptation. There is uncertainty about observed climate change and its past effects on natural and human systems. Projections of future climate change and associated impacts are also uncertain, which presents a great challenge at all levels of policy and decision-making. In the short to medium term, changes may be subtle in the context of the natural internal variability of the climate system. In the longer term, i.e. after 2030, uncertainty will gradually come to be dominated by uncertainty in the ambition and effectiveness of future international actions to address the drivers of climate change, i.e. to the mitigation of emissions of greenhouse gases (GHGs). The state at which the global climate systems will stabilise will be largely determined by the cumulative global emissions of carbon dioxide from fossil fuels and land use change (IPCC, 2013). This will determine the full extent of climate change and the level of adaptation that will be required.

Nationally, uncertainties exist in relation to both the rate and extent of the impacts that Ireland will experience. In the short to medium term, these uncertainties are primarily due to the inherent variability and the chaotic nature of the climate system. The chaotic nature of the weather/climate system is a fundamental source of uncertainty, which is amplified by climate change. Uncertainty is not uniform: some weather elements (e.g. precipitation, weather extremes) are inherently "noisy", while others (e.g. temperature) are more predictable. The physical linkage of GHGs with atmospheric temperature will ensure that the projected influence of climate change on the latter will be subject to less uncertainty than that for precipitation, which may remain subject to considerable uncertainty at a regional level in the short to long term.

In this regard, it is important that any assessment of the need and level of adaptation must first consider how communities, sectors and localities currently interact with weather and a variable climate.
While there is less certainty about the short-term predictability of climate change and extreme weather events, there is a consensus that both global and regional climates are changing and, thus, there are greater levels of certainty about the gradual trends we can expect for Ireland's climate.

The report provides a summary of observed and projected changes in the Irish climate across a number of key parameters. It also synthesises knowledge of ongoing and anticipated climate change impacts across a number of environmental and economic sectors. Finally, it presents recommendations for further steps required to support policy development and aid the implementation of adaptation nationally.
In order to facilitate this process, an adaptation framework is needed. This would aim to advance work within and across sectors and at a number of levels, through further development of the knowledge base, building capacity, communication of scientific knowledge and the implementation of actions. This adaptation framework would enable synergies between groups, generate understanding and learning (especially in relation to cross-cutting issues) and avoid maladaptation.

Advancing the knowledge base

- Development and sustained support of observation systems for essential climate variables and analysis of trends and changes.
- Improvement of climate projections and near-time climate forecasting, e.g. periods from years to decades as well as mid- and end of century information.
- Support for the development of analysis of fundamental physical processes that drive the rate and extent of climate change, e.g. ocean systems and precipitation.
- Greater understanding of slow-onset climate change and abrupt changes.

Further development of sectoral risk and vulnerability assessments

- A national-level climate change risk assessment is required to set out priority climate risks for Ireland

and provide analysis of the implications of cross-sectoral and cumulative risks and external climate impacts (e.g. on human migration, markets, supply chain management). In time, it would be expected that this high-level national assessment will be supported by sectoral and locally specific vulnerability/sensitivity analysis.
- Possible opportunities for Ireland should be identified (e.g. agriculture, tourism, industry).
- Any new approaches to climate risk management should ideally be placed within an adaptive risk management framework.

Development of adaptation options, including costs and benefits

- A full range of adaptation options must be included in decision-making, with particular attention focusing on green approaches (e.g. green infrastructure).
- The costs of current and future climate change impacts and adaptation must be established for a range of key sectors. This must be based on a consistent framework applicable across all sectors and relevant to different types of impact to ensure comparability and consistency in the use of climatic and socio-economic projections. The role of the insurance industry must be established, particularly in response to extreme weather events.
- Development of cross-sectoral comparative metrics and indicators to enable high-level assessment of the scale and urgency of adaptation requirement.
- Tools for the assessment of the effects on other sectors, up- or downstream effects and in supply chains, macroeconomic (general equilibrium) effects, changes in behaviour as a result of changes in risk exposure (moral hazard risk) of adaptation measures.
- Information must be made available on sources of funding/finance for adaptation actions.

Development and implementation of effective governance structures

- Further and deeper horizontal and vertical co-ordination of adaptation efforts as the implementation of adaptation progresses.
- The participation of multiple stakeholders, including the business and local communities, must be explored with a view to ratcheting up adaptation action at all levels of decision-making.

1 Introduction

Warming of the climate system is unequivocal and it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. Observations show that global average temperatures have increased by 0.85°C (in the range 0.65–1.06°C) since 1850 (IPCC, 2013a). The atmosphere and ocean have warmed, the amount of snow and ice has diminished, the sea level has risen and the concentrations of greenhouse gases (GHGs) in the atmosphere have increased (IPCC, 2013a). Since the 1950s, many of the observed changes have been unprecedented over periods of decades to millennia. The impacts are observed on natural and human systems on all continents and across the oceans. Evidence of climate change impacts is clearest in natural systems (IPCC, 2014a).

Projections of future global and regional climate change under all Intergovernmental Panel on Climate Change (IPCC) representative concentration pathways (RCPs) scenarios demonstrate that continued emissions of GHGs will cause further warming and changes in the components of the climate system.

Changes in Ireland's climate are in line with and similar to relevant global trends. Temperatures have increased by 0.8°C since 1900: an average of 0.07°C per decade over that period (Dwyer, 2012). As a result of the slow response time (inertia) of the climate system, changes are projected to continue and increase over the coming decades. Even if GHG emissions could be stopped immediately, some impacts, such as sea level rise (SLR), are projected to continue up to and beyond the end of this century.

Climate change will have diverse and wide-ranging impacts on Ireland's environment, society, economic sectors and natural resources. These include managed and natural ecosystems, water resources, agriculture and food security, human health, and coastal infrastructures and zones (Coll and Sweeney, 2013; Coll *et al*., 2014).

Box 1.1. Drivers of climate change

Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change. According to the IPCC (2013a), it is *extremely likely* that more than half of the observed increase in global average temperature from 1951 to 2010 was caused by an anthropogenic increase in GHG concentrations and other anthropogenic forcings.

The attribution of specific extreme events to anthropogenic climate change, i.e. establishing a robust causal link, is very challenging. However, there has been significant progress in this area in recent years, especially in terms of the analysis of the change in probability of a specific type of event due to the influence of climate change.

Case study

In the summer of 2003, anthropogenic climate change increased the risk of heat-related mortality in central Paris by ~70% and by ~20% in London, which experienced lower levels of extreme heat. Out of the estimated ~315 and ~735 summer deaths attributed to the heatwave event in Greater London and central Paris, respectively, 64 (±3) deaths were attributable to anthropogenic climate change in London and 506 (±51) in Paris (Mitchell *et al*., 2016).

This type of analysis has yet to be undertaken in a systematic manner for extreme events in Ireland. However, Storm Desmond, 4–6 December 2015, was analysed by van Oldenborgh *et al*. (2015), who found that the similar extreme rainfall events across the UK were about 40% more likely to occur as a result of climate change.

1.1 Analyses of Climate Change in Ireland

1.1.1 Observed climate change

Observations of the climate system are based on direct measurements and remote sensing from satellites and other platforms. Systematic instrumental observations of the weather covering large geographical regions did not appear until the mid-19th century. Paleoclimate reconstructions extend some records back hundreds to millions of years. Together, they provide a comprehensive view of the variability and long-term changes in the atmosphere, the ocean and the land surface.

The availability of high-quality climate observations is a critical starting point from which an understanding of past and emerging trends in the current climate can be developed. They are also essential to help build robust projections of future climate (Dwyer, 2012).

Met Éireann holds an important archive of meteorological data for Ireland. Some records extend back more than 100 years. These data are subject to ongoing development and analyses and are reported to international databases. McElwain and Sweeney (2007) and Gleeson *et al*. (2013) have provided analyses of these records in line with international standards, e.g. the data are referenced to the standard 30-year average. Other sources of data and analysis include the Office of Public Works (OPW), the Marine Institute and the Environmental Protection Agency (EPA).

Ireland has important long-term records of flora and fauna. These are reported to international databases, e.g. European Phenology Network (http://www.pik-potsdam.de/~rachimow/epn/html/frameok.html). Analyses of flora and fauna show that natural systems in Ireland are reacting to climate change. These patterns of change are similar to those that are occurring at regional and global levels as reported by the IPCC (2014a).

Paleoclimate analysis and other archives provide information on climate conditions in Ireland over periods outside the historical records. These data provide important information on climate variability and the stability of key factors that determine Ireland's climate such as the meridional overturning circulation (MOC) associated with the Gulf Stream. Projections of the long-term stability of the MOC remain highly uncertain; however, it is notable that many model projections show a cool region developing in the North Atlantic. This feature has already shown signs of emergence in the observation data (Rahmstorf, 2015).

1.1.2 Projected climate change

Global climate models (GCMs) provide projections of future climate conditions based on different atmospheric GHG concentrations or, more broadly, different levels of radiative forcing of the climate system. The IPCC AR5 WG1 report (2013) provided the most recent systematic analysis of outputs from a range of GCMs. These models simulate changes based on a set of scenarios of anthropogenic forcings.

Box 1.2. IPCC representative concenration pathways

One of the more intractable sources of uncertainty in providing projections of climate change is the fundamental uncertainty in future emissions of GHGs. Emissions of GHGs will depend on future economic development, the rate of adoption of renewable technologies and other socio-economic factors, which are difficult to predict.

To address this, climate model projections are driven by scenarios of natural and anthropogenic forcings, the standard set for the IPCC AR5 reports being the RCPs. The RCPs describe four possible climate futures, all of which are considered possible depending on how much GHG is emitted in the years to come. The four RCPs – RCP2.6, RCP4.5, RCP6 and RCP8.5 – are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0 and +8.5 W/m^2, respectively). Figure 1.1 presents the radiative forcing of the RCPs for the period 2000–2100. For this reason, climate scientists are very careful in their use of language, and make it very clear that the outputs of climate models are projections of climate change, which are based on these scenarios, and are not predictions or forecasts of climate change.

RCPs and radiative forcing

Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth–atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. In this report, radiative forcing values are for changes relative to pre-industrial conditions defined at 1750 and are expressed in watts per square metre (W/m^2) (IPCC, 2007).

The numbers in the RCPs refer to the radiative forcings, expressed in W/m^2, for possible climates in the year 2100, relative to the pre-industrial era. Total radiative forcing is determined by both positive (warming) forcing from GHGs and negative (cooling) forcing from aerosols. The dominant factor is the positive forcing from carbon dioxide (CO_2). As the radiative forcing increases, the global temperature at the surface rises.

RCP primary characteristics

RCP2.6 – low emissions

Radiative forcing reaches 3.1 W/m^2 before it returns to 2.6 W/m^2 by 2100. In order to reach such forcing levels, ambitious GHG emissions reductions would be required over time.

> This future is consistent with: Rapid decline in the use of fossil fuels; Low energy intensity; Use of croplands increase due to bio-energy production; More intensive animal husbandry; Methane emissions reduced by 40%; Global CO_2 emissions stable at today's levels up to 2020, then decline and become negative by 2100; Atmospheric CO_2 concentrations peak around 2050, followed by a modest decline to around 400 ppm by 2100. (Bjørnæs, 2010)

RCP4.5 – intermediate emissions

Radiative forcing is stabilised shortly after 2100, but consistent with a future with relatively ambitious emissions reductions.

> This future is consistent with: Lower energy intensity; Effective reforestation programmes; Decreasing use of croplands and grasslands due to yield increases and dietary changes; Effective climate policies; Stable methane emissions; CO_2 emissions increase only slightly before decline commences around 2040. (Bjørnæs, 2010)

RCP6 – intermediate emissions

Radiative forcing is stabilised shortly after 2100, which is consistent with the application of a range of technologies and strategies for reducing GHG emissions.

> This future is consistent with: Heavy reliance on fossil fuels; Intermediate energy intensity; Increasing use of croplands and declining use of grasslands; Stable methane emissions; CO_2 emissions peak in 2060 at 75% above today's levels, then decline to 25% above today. (Bjørnæs, 2010)

RCP8.5 – high emissions

This RCP is consistent with a future with no policy changes to reduce emissions. It is characterised by increasing GHG emissions that lead to high GHG concentrations over time.

> This future is consistent with: Continued growth in CO_2 emissions; Rapid increase in methane emissions; Increased use of croplands and grassland which is driven by an increase in population; Low rate of alternative technology development; No implementation of climate policies. (Bjørnæs, 2010)

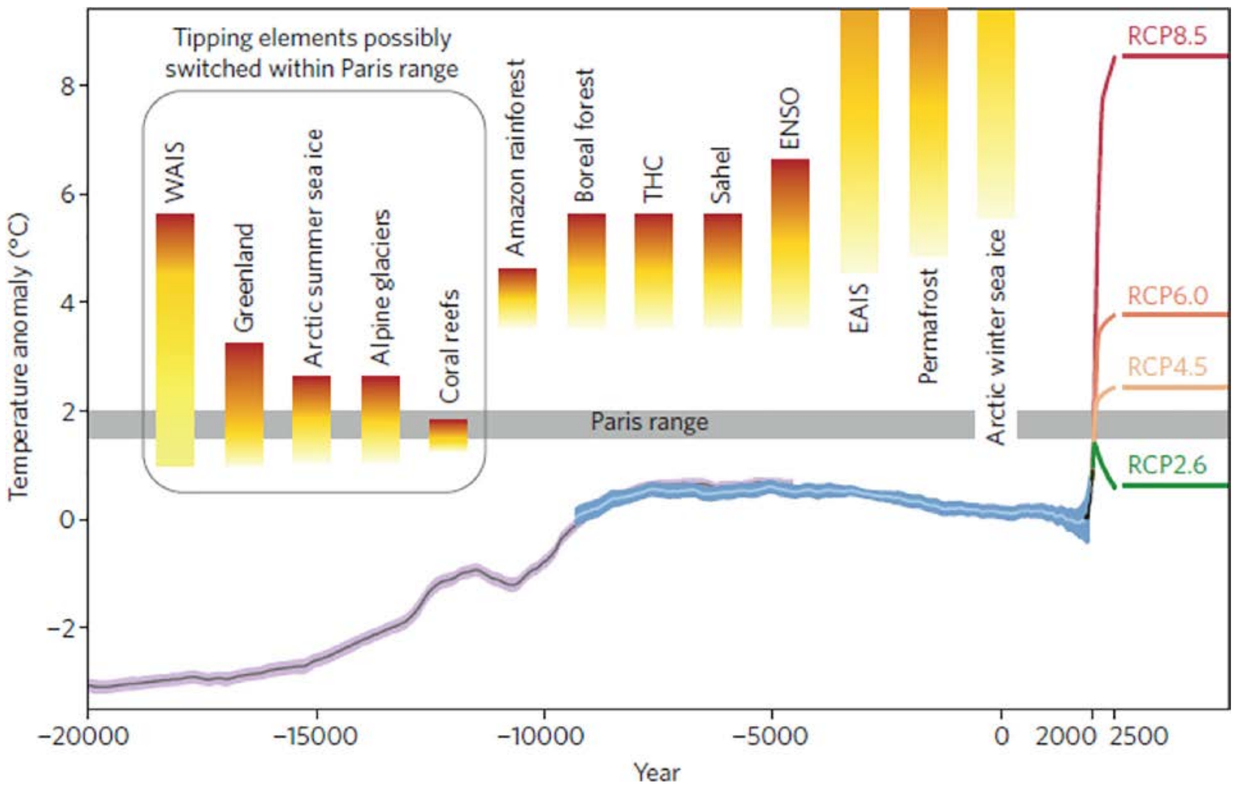

Figure 1.1. Tipping elements in context of the global mean temperature evolution. The global mean surface temperature evolution from the Last Glacial Maximum to the Holocene is shown as grey and light blue lines and the purple and blue shading shows one standard deviation; this is based on palaeoclimatic proxy data, instrumental measurements since 1750AD (HadCRUT data, black line) and different future global warming scenarios. Threshold ranges for crossing various tipping points where major subsystems of the climate system will be destabilised are shown, follow the tipping point definition of Lenton *et al*. 2007; this does not require irreversibility, so sea ice cover is included. The range for the West Antarctic Ice Sheet (WAIS) has been adapted to account for the observation that a part of it has probably tipped already. Reproduced with the permission of Macmillan Publishers Ltd from Schellnhuber *et al*., 2016. THC, thermohaline circulation; ENSO, El Niño Southern Oscillation; EAIS, East Antarctic Ice Sheet.

Table 1.1. Mean ensemble projected change (anomalies) in global mean surface temperature for the mid- and late 21st century, relative to 1986–2005. Likely ranges are calculated from projections as 5–95% model ranges

Scenario	Global mean surface temperature change (˚C)			
	2046–2065		2081–2100	
	Mean	Likely range	Mean	Likely range
RCP2.6	1.0	0.4–1.6	1.0	0.3–1.7
RCP4.5	1.4	0.9–2.0	1.8	1.1–2.6
RCP6.9	1.3	0.8–1.8	2.2	1.4–3.1
RCP8.5	2.0	1.4–2.6	3.7	2.6–4.8

Source: IPCC, 2013a.

A new set of scenarios developed by the IPCC (2013a), the RCPs, were used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme (IPCC, 2013a). The RCPs define four possible scenarios for global GHG concentrations until 2100 (Box 1.2).

It is worth noting that only those global emissions trajectories consistent with RCP2.6 project global warming within the range identified as a target under the Paris Agreement (2015). Given the challenges implicit in achieving the goals of the Paris Agreement, it is important that decision-makers consider the range of projections under each of the RCPs and measure the vulnerabilities and risks according to their own circumstances.

GCMs currently provide analysis at horizontal resolutions typically in the range 100–300 km, although some models have been run at finer resolutions. This provides insight into the broader regional characteristics of potential climate change. However, since climate fields such as precipitation and wind speed are closely correlated to the local topography, this resolution may be inadequate for the simulation of the detail and pattern of climate change on the scale of a region the size of Ireland.

To overcome this limitation, the regional climate model (RCM) method dynamically downscales the coarse information provided by the global models and provides high-resolution information on a sub-domain covering Ireland.

Recently, RCMs were run at high spatial resolution, a maximum of 4 km, thus allowing for a better evaluation of the potential local effects of climate change. Since RCMs have a better representation of coastlines and general topography, the resulting model output is more useful for focused climate change impact studies (Nolan, 2015).

To address the issue of uncertainty, a multi-model ensemble approach was employed (Table 1.2). Specifically, the future climate of Ireland was simulated using three different RCMs, driven by four GCMs. To account for the uncertainty in future emissions, a number of Special Reports on Emission Scenarios (SRESs)[1] (B1, A1B, A2) and RCP (4.5, 8.5) emission scenarios were used to simulate the future climate. Through the ensemble approach, the uncertainty in the RCM projections can be partially quantified, thus providing a measure of confidence in the predictions. However, it should be noted that any schematic bias inherent in the GCMs will be transposed to the outputs of the RCMs. Therefore, it is very important to compare both parent GCM and daughter RCM outputs with observation data to appreciate the potential limitations of projections.

Table 1.2. Ensemble of RCM simulations (Nolan, 2015)

RCM	GCM	Scenario (number of simulations)	Period	Grid spacing
Group 1				
CLM3	ECHAM5	Historical (2)	1961–2000	7 km
CLM3	ECHAM5	A1B (2), B1 (1)	2021–2060	7 km
Group 2				
CLM4	ECHAM5	Historical (2)	1961–2000	7 km
CLM4	ECHAM5	A1B (2)	2021–2060	7 km
Group 3				
CLM4	CGCM3.1	Historical (1)	1961–2000	4 km
CLM4	CGCM3.1	A1B (1), A2 (1)	2021–2060	4 km
Group 4				
CLM4	HadGEM2-ES	Historical (1)	1961–2000	4 km
CLM4	HadGEM2-ES	RCP4.5 (1), RCP8.5 (1)	2021–2060	4 km
Group 5				
CLM4	EC-Earth	Historical (3)	1981–2009	4 km
CLM4	EC-Earth	RCP4.5 (3), RCP8.5 (3)	2021–2060	4 km
Group 6				
WRF	EC-Earth	Historical (3)	1981–2009	6 km
WRF	EC-Earth	RCP4.5 (3), RCP8.5 (3)	2021–2060	6 km

1 The SRES is a report by the IPCC that was published in 2000. The GHGs emissions scenarios described in the report have been used to make projections of possible future climate change. The SRESs were used in the IPCC Third Assessment Report (2001) and in the IPCC Fourth Assessment Report (2007).

1.2 Tipping Points

Climate scenarios reveal slow evolutions of, among others, temperature and precipitation, which follow the rising GHG concentrations with a certain delay. In addition to these slow evolutions, climate change may also lead to more abrupt changes. This possibility is referred to as a tipping point within the climate system.

The precise levels of climate change sufficient to trigger tipping points remain uncertain, but the risk associated with crossing multiple tipping points in the Earth system or interlinked human and natural systems increases with rising temperature (IPCC, 2014a). For example, the major ice sheets in Greenland and Antarctica are vulnerable to a class of tipping point event whereby the threshold for inevitable loss of ice can be crossed, but the onset is slow, with impacts accumulating over a few centuries.

Figure 1.1 roughly divides the temperature space into four qualitatively distinct domains. The first one embraces the range between the Last Glacial Maximum and the Holocene Climate Optimum in which the pre-industrial human enterprise was born (purple line). The second domain covers temperature ranges between 1°C and 3°C and thus includes the Paris range. From Figure 1.1, it is immediately apparent that, even if global warming is limited to below 2°C, some important tipping elements may already be harmed or transformed. In fact, the tipping point for marine ice sheet instability in the Amundsen Basin of West Antarctica may well have been crossed already, and the risk of crossing further tipping points will increase with future warming. Progressing into the third domain with global warming reaching 3–5°C would seriously harm most tipping elements. For warming levels beyond this range (spanning the fourth domain), the world as we know it would be bound to disappear.

Traditionally, tipping points are estimated as having a low probability of occurrence, but a great impact on society. Policy-relevant climate issues that could be linked to potential future tipping elements in the climate systems include:

- loss of mass of the Greenland and West Antarctic ice sheets;
- loss of Arctic sea ice and the Alpine glaciers – the most vulnerable sensitive elements for global warming;
- changes in the Atlantic thermohaline circulation (THC).

The THC is part of a large-scale ocean circulation that contributes to milder winters in northern Europe when compared with regions at a similar latitude in North America and northern Asia. A change in the THC is caused by changes in the salinity of the North Atlantic Ocean. That is why this sensitive element is linked only indirectly to global warming, through melting of the Greenland ice sheet and changes in (Arctic) precipitation. The probability of collapse of this circulation is estimated to be low, even for high temperatures. However, changes in the intensity of the THC may have significant impact regionally without actually crossing the tipping point for collapse (Lenton *et al*., 2007).

1.3 International Commitments: The Paris Agreement and Implications

The Paris Agreement commits 196 countries to the mitigation goal of limiting global temperature rise to well below 2°C. According to the IPCC AR5 report, to achieve this 2°C objective, global GHG emissions must be reduced by 40–70% by 2050 compared with 2010 and be zero or below in 2100. This would be broadly consistent with RCP2.6.

Current commitments to reduce emissions, however, even if fully implemented, will lead to an estimated 2.7°C rise, consistent with RCP4.5.

Global emissions would need to peak soon and then decline rapidly for the Paris Agreement goals to be feasible. Even in this scenario, the uncertain sensitivity of the climate to GHGs means that there would remain at least a small chance of warming of 4°C or more by 2100. It is therefore prudent to prepare for further warming while pursuing more ambitious emission reductions as part of the global effort.

The Paris Agreement is clear that, if mitigation actions succeed in limiting the rise in global temperature, less adaptation will be needed to deal with the consequences of climate change.

1.4 Risk and Uncertainty

The IPCC AR5 WG1 Report 2013 outlines developments and progress in GCMs. However, uncertainties remain. These uncertainties increase at regional and local levels where spatial, geographical and/or local factors can dominate climate conditions. The IPCC has developed methods to assess and convey such uncertainties, e.g. through describing confidence levels. The robustness of trends and projections in the main climate variables are expressed here using this confidence level terminology, which is in line with the definitions set out in the IPCC AR5 reports. However, note that for the most part the statements of confidence in this report are based on polling expert judgement,[2] rather than on the more analytical approach possible for IPCC global assessment. This is due to variability in Ireland's climate and a current lack of RCM model outputs to tease out more robust statistical descriptions of uncertainty. For an in-depth discussion of this terminology we refer the reader to Stainforth *et al*. (2007).

The implications of uncertainties and how they can be addressed in the development and implementation of adaptation actions varies according to the sector, issue or location being considered. Guidance on how to manage uncertainty in decision-making is beyond the scope of this report, but reference material includes Willows and Connell (2003) and Walker *et al*. (2013). In the short to medium term, uncertainties are primarily due to scientific uncertainties such as inherent variability and the chaotic nature of some of the phenomena being considered, e.g. rainfall and wind regimes. In the longer term, i.e. after 2030, the dominant uncertainty is primarily the ambition and effectiveness of future international actions to address the drivers of climate change, i.e. to reduce emissions of GHGs. This will eventually determine the full extent of climate change and the level of adaptation that will be required.

However, uncertainties should not be taken as an excuse for inaction in addressing climate change. There is overall agreement on the robustness of trends and projections of key climate variables and associated impacts such as temperature and SLR at global and continental scale. However, many uncertainties will remain, especially with regard to precipitation and extreme climate events at a regional and local level, where the information is needed most. Climate change uncertainty adds to the variety of other decision criteria that decision-makers have to deal with in their day-to-day activities. However, climate information, including its associated uncertainty, can still be very informative. Many methodologies exist to take potential climate change impacts into account in policy development and investment decisions that recognise uncertainties but do not require precise and accurate quantification (robust decision-making). Rather than a barrier to action, uncertainty can be treated as a motivation towards a precautionary approach.

Watkiss and Hunt (2012) made a case for a strategy of decision-making under uncertainty that allows public and private organisations and households to learn as they go. This can be achieved by introducing the principles of robust adaptation into an adaptive risk management framework. Central to the approach are the following policy criteria:

- reversible;
- provide margins of safety, e.g. in the design of infrastructure;
- prioritise soft strategies without high sunk costs or fixed engineering;
- reduce the decision time horizon of investments;
- reduce long-term commitments.

The development of actions on adaptation also requires appropriate approaches, such as vulnerability assessment and risk management, to address uncertainties. Iterative risk management is a useful framework for decision-making in complex situations characterised by large potential consequences, persistent uncertainties, long timeframes, potential for learning, and multiple climatic and non-climatic influences changing over time (IPCC, 2014a).

1.5 Climate Change Impacts in Ireland

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans (IPCC, 2014a). Climate change is expected to create new risks for natural and human systems and amplify existing risks in countries at all levels of development (IPCC, 2014a). Ireland is already observing the impacts of climate change on natural and human systems.

2 Expert review of the Second Summary of the State of Knowledge Report was held in Dublin on 4 September 2015. The attendees are listed in Appendix 1.

The combination of warming temperatures and melting ice sheets and glaciers is causing the global sea level to rise, which presents a growing threat to vital coastal ecosystems and millions of people around the world who live in coastal regions. This threat includes both the gradual upwards creep in sea level and periodic, catastrophic ocean surges associated with land-falling cyclones. Ireland, as an island with soft coastlines, is already observing the impacts of SLR (Dwyer, 2012).

A warmer atmosphere has a greater capacity to hold water vapour. Consequently, climate models project that global warming will tend to cause wet regions to get wetter and dry regions to get drier. According to the IPCC (SRES Report, 2012), there is medium confidence that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions. Ireland's geographic location makes it particularly difficult to present projection outputs with high confidence. The North Atlantic moderates our climate, and ocean areas near Greenland show signs of local cooling, which, if sustained, may impact on Irish weather and climate in unexpected ways, notwithstanding the wider regional and global warming trends (Rahmstorf, 2015). Therefore, although this report represents best available knowledge, which points to continued warming patterns of climate change, there is a chance that regional cooling may increase the climatic contrast between continental Europe and the Atlantic, with Ireland positioned at a highly variable and volatile interface.

1.6 Structure of Report

This report presents a summary of the current state of knowledge on climate change and expected impacts for Ireland. It will be of use to policymakers, sectoral and local decision-makers and stakeholders interested in or working on adaptation to climate change.

This report is not intended as a national risk assessment, as it does not undertake sectoral or local-level climate sensitivity/vulnerability assessment or determine specific risks and opportunities for Ireland. Rather, the report provides an overview of key climate hazards for those entrusted with developing their own sectoral or local climate risk assessments. We understand these as "Tier 1" risks, which should provide the basis for initial climate risk screening when developing adaptation strategies and progressing actions that enhance climate resilience, implementation and investment.

The information in Chapter 2 on observations and projections is largely based on work carried out by Met Éireann, Maynooth University, University College Dublin, University College Cork, the Irish Centre for High End Computation (ICHEC) and material from the IPCC AR5 WG1 Report (2013b). This element of the report has also been supplemented by expert opinion elicited through workshops and written submissions. The report focuses on data and information on key climatic parameters of the atmosphere, terrestrial, hydrological and ocean domains.

Information in Chapter 3 on sectoral impacts is drawn from IPCC AR5 WG2 Report (2014b) and Irish-based research. Synthesised material is also drawn from Ireland's climate information platform: Climate Ireland (http://www.climateireland.ie/#/). Headline impacts are outlined for a number of sectors, including: critical infrastructure and built environment, industry and insurance, agriculture, forestry, peatlands, biodiversity and ecosystems, marine and fisheries, tourism, water management and resources, and human health. In this way, the report structure is similar to the earlier report from 2009. We also present a set of possible adaptation options for managing climate risks. This is not an exhaustive list, but rather outlines the possible range of management responses available in different situations and for differing timelines. In reality, the value of each of these options will need to be assessed according to criteria such as efficacy, cost and timelines using an approach such as multi-criteria analysis.

Finally, we present recommendations for further steps, which are required to support the development of policy and the implementation of adaptation in Ireland.

2 Current Knowledge on Climate Change for Ireland

A summary of observed and projected climate change across key domains of atmosphere, terrestrial and hydrology, and oceans is presented. The "scientific confidence" in the validity of these findings is described according to five qualifiers: very low, low, medium, high and very high.[3]

2.1 Atmosphere: Air Temperatures, Precipitation and Extreme Weather

See Tables 2.1–2.3.

Air temperature: Surface air temperature is a key climate variable. Temperatures in Ireland increased by about 0.8°C over the period 1900–2011. The decadal trend is 0.07°C averaged over the period 1900–2011. The standard measurement of temperature in the atmosphere is taken at synoptic and climatic stations across Ireland. The analysis is based on up to 100 years of records (and over 100 years for certain stations).

Precipitation: The localised nature and temporal variability of precipitation makes it less amenable to statistical analyses. In Europe the number of very wet days has increased over the last 50 years (Dwyer,

Table 2.1. Observed and projected changes for temperature in Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Air temperature	Mean annual surface air temperature has increased by approximately 0.8°C over the last 110 years (Dwyer, 2012)	High	National: projections for mid-century indicate an increase of 1–1.6°C in mean annual temperatures, with the largest increases seen in the east of the country (Gleeson *et al*., 2013; Nolan, 2015)	Medium/high
	All seasons are warmer; summer and winter minimum temperatures have tended to be higher than the 1961–1990 average, in particular over the last 20 years (Walsh and Dwyer, 2012)	High	All seasons are projected to be significantly warmer (0.9–1.7°C) by mid-century (Nolan, 2015)	Medium/high
	The changes also show regional variation. Warming is more pronounced at the extremes (i.e. hot or cold days) and in winter night-time temperatures (Nolan *et al*., 2013)	High	Warming is enhanced for the extremes (i.e. hot or cold days), with highest daytime temperatures projected to rise by up to 2.6°C in summer and lowest night-time temperatures to rise by up to 3°C in winter (Nolan, 2015)	Medium
	Heatwaves: the number of warm days has increased (Walsh and Dwyer, 2012)	High	Increased frequency of heatwaves	Medium
	Cold snaps/frost days/nights: the number of frost days has decreased (Walsh and Dwyer, 2012)	High	National (mid-century): averaged over the whole country, the number of frost days (days when the minimum temperature is below 0°C) is projected to decrease by over 50%. Similarly, the number of ice days (days when the maximum temperature is below 0°C) is projected to decrease by typically 75%. The projected decrease in the number of ice days is greatest in the north (Nolan, 2015)	Medium

3 Confidence in the validity of a finding synthesises the evaluation of evidence and agreement. Scientific confidence in projection refers to the likelihood, or probability, of some well-defined outcome having occurred or occurring in the future (IPCC, 2013a).

Table 2.2. Observed and projected changes for precipitation in Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Precipitation	Increase in average annual national rainfall of approximately 60 mm or 5% in the period 1981–2010, compared with the 30-year period 1961–1990 (Walsh and Dwyer, 2012)	Medium	Results show significant projected decreases in mean annual, spring and summer precipitation amounts by mid-century. The projected decreases are largest for summer, with reductions ranging from 0% to 20% (Nolan, 2015)	Low/medium
	In general, the larger increases in rainfall are recorded in the western half of the country (Walsh and Dwyer, 2012)	Medium (low confidence for local detail and very low confidence for extremes)	The number of extended dry periods (defined as a time period of at least 5 consecutive days for which the daily precipitation is less than 1 mm) is also expected to increase substantially (5–35%) by mid-century over the full year and during autumn and summer (Nolan, 2015)	Low/medium
	An analysis of seasonal rainfall over the same period shows small increases in all seasons over recent decades; however, the spatial distribution and intensity vary (Walsh and Dwyer, 2012)		National (mid-century): the expected decreases in precipitation are largest for summer with values ranging from 10% to 20%. The expected increases in dry periods are also largest for summer with projected values of ~35% (Nolan, 2015)	Medium
	Less snow days	High	Less snow throughout	Medium/high
	Drier summers	Medium (2007 and 2008 were anomalous but did not reverse trend)		Medium

2015). In the Irish context precipitation refers almost exclusively to rainfall, although snow and hail are included in the definition. Precipitation is measured at synoptic and climatic stations across Ireland.

Extreme weather and climate events: This refers to the occurrence of an intense or atypical weather or observation of a climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. Generally, both extreme weather events and extreme climate events are referred to collectively as "climate extremes" (IPCC, 2012). Events can include storms (speed and direction are two key measurements used to characterise wind and provide information on the strength and frequency of weather systems), flooding (pluvial, fluvial or coastal, with coastal flooding linked to storm surge and/or wave action), sea surges, and hot and cold days. Studies have shown that the intensity and frequency of extreme events are changing and will change further as a result of climate change (IPCC, 2013a). The character and severity of impacts from climate extremes depends not only on the extremes themselves, but also on exposure and vulnerability to these extremes (IPCC, 2012).

Large-scale circulation: This refers to patterns of weather and ocean currents, which occur on spatial scales of the order of thousands of kilometres. An important example is the Gulf Stream in the Atlantic Ocean; in the atmosphere the westerly airflow is the dominant weather pattern that affects the Irish climate.

2.2 Terrestrial and Hydrological

See Tables 2.4–2.6.

Soil temperature is measured throughout Ireland by Met Éireann, Teagasc and other bodies. In general, measurements are made in the surface layers of the soil most pertinent to microbial activity and plant growth and development.

Ground and surface water runoff and fresh water temperatures: Information regarding surface and groundwater is based on the National Water Quality Monitoring Network, which comprises EPA, OPW and local authority facilities.

Phenology is the study of the timing of recurring natural events (both terrestrial and marine) and includes leaf unfolding, bird migration and the

Table 2.3. Observed and projected changes for synoptic variables for Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Extreme weather and climate events	Storms: summer storm tracks over Europe are dominated by internal variability over the past millennium (Gagen *et al*., 2016). A review of storminess over the North Atlantic (Feser *et al*., 2015) suggests that most long-term studies show merely decadal variability for the last 100–150 years; there is no evidence of a sustained long-term trend	Low confidence	Slightly fewer storms, but more intense ones. The tracks of intense storms are projected to extend further south (Nolan, 2015) However, uncertainty on details remains high (Matthews *et al*., 2016)	Low/medium
	Flooding: for the period 1954–2008 summer mean flows are dominated by increasing trends, while there is a tendency for increases in winter mean flows for longer record stations (Dwyer and Murphy, 2012)	Medium/high	Using impact models, a robust signal of increasing seasonality in hydrological regimes is evident, with increases in winter and spring stream flows and a decrease in summer stream flow likely. A 20% increase in the amount of water flowing through rivers is expected for the majority of catchments by mid- to late century, while for summer decreases of over 40% (those with little groundwater storage in particular) have been simulated for the end of the century (Murphy and Charlton, 2007; Steele-Dunne, 2014)	Medium
Large-scale circulation	Atmospheric: no discernible change in large-scale circulation patterns affecting Ireland	Medium	Atmospheric**:** possible greater frequency of blocking high-pressure systems; increased risk of prolonged heatwave events. While some studies link declining Arctic Sea ice with cold continental air outbreaks, across Europe the implications for the future climate are less clear (Vihma, 2014)	Low
	Ocean**:** no coherent trends observed, significant interannual variability impacts on large-scale hydrographic conditions and climate		Ocean**:** THC may slow during the 21st century	Low

Table 2.4. Observed and projected changes for soil temperature for Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Soil temperature	The changes are consistent with the observed changes in air temperature	Medium	Consistent with air temperature: warmer in the south-east	Medium
Ecosystem carbon	It is difficult to estimate the impact of climate change on carbon pools, as management practices, such as soil drainage and peat extraction, have a much larger impact on carbon loss. However, there has been a significant net uptake of carbon to biomass, in recent years, primarily as the result of an active afforestation programme	Medium	In general, longer growing seasons and wetter conditions would encourage the uptake of carbon to ecosystems. However, prolonged dry periods can have an adverse impact on carbon pools (Bahn, 2013; Khalil, 2013)	High

Table 2.5. Observed and projected changes for hydrological variables for Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Surface water (rivers and lakes) and runoff	Rivers: analysis of long records of annual mean flows shows a tendency for increasing flows	Low or very low for extremes	Intensification of the hydrological cycle, leading to both increased incidences of high- and low-flow periods (Coll *et al*., 2014)	High confidence on intensification based on physical reasoning Medium/low confidence on changes in floods and droughts
	Summer mean river flows are dominated by increasing trends, while there is a tendency for increases in winter mean flows for longer record stations (Dwyer and Murphy, 2012)	Medium	Increased flow to rivers in winter and less in summer	Medium confidence
	Lakes: no systematic analysis of lake levels has been carried out to date (Dwyer, 2012)	N/A	More intense rainfall patterns may lead to higher volumes of runoff at peak times, increasing the risk of flooding	Medium confidence
Groundwater	Groundwater: no systematic analysis of national groundwater levels has been carried out to date (Dwyer, 2012) However, regional analysis of long-term groundwater level trends in the SERBD was undertaken to investigate if any impacts of climate change were evident in groundwater levels. The analysis showed no consistent change in the timing of groundwater level minima or maxima in the SERBD (Tedd *et al*., 2011)	N/A	SLR may lead to salination of groundwater systems in coastal areas (Williams, 2007)	N/A
Surface freshwater temperatures	Probably consistent with air and soil temperatures	Low/medium	Consistent with air and soil temperatures	Low/medium

N/A, not available; SERBD, South Eastern River Basin District.

Table 2.6. Observed and projected changes for phenology and climate space changes for Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Phenology	Terrestrial: longer growing season; earlier spring	High/medium	Longer growing season; earlier spring	High
	Trees and plants: evidence of change in timing of phenological phases such as bud burst, leaf unfolding, flowering, fruiting, leaf colouring and leaf fall in some trees and plants (Donnelly *et al*., 2013)	High/medium	Projections suggest that bud burst of birch will continue to advance at least until 2100, but the rate of advance will vary across the country with the north-east showing the greatest advance (Caffarra *et al*., 2013a)	High/medium
	Birds: change in the timing of arrival and departure of a wide range of birds, including land and seabirds and winter and summer migrants, to Ireland has been observed (Stirnemann *et al*., 2013). These changes generally resulted in earlier arrival and departure in spring, which in turn was correlated with rising spring temperature	High/medium	Further change linked to temperature change	High

Table 2.6. Continued

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
Phenology	Moths/butterflies: species analysed exhibited an advance in first sighting and a subsequent lengthening of the flight period (O'Neill *et al.*, 2012). There was an observed northwards shift in the butterfly community with some species that were once confined to the southern half of the country expanding their range (O'Regan, 2013)	High/medium	Further increases in annual temperatures in Ireland will further affect the ecologies of Irish butterflies, in particular their flight periods, voltinism and abundances (O'Regan, 2013)	High
	Habitats: widespread changes are already occurring in natural systems and these will continue. Results for Ireland reinforce the strongly emerging global consensus that climate-driven changes will profoundly affect our ability to conserve species and the habitats on which they depend (Coll *et al.*, 2013, 2014)	High/medium	Species representative of arctic-montane biomes will be most vulnerable to climate change. On the island of Ireland, these species will not have higher altitudes and latitudes to move to (Coll *et al.*, 2013). Active blanket bog and other wetland habitats are regionally vulnerable to the impacts of climate change (Coll *et al.*, 2013, 2014)	Medium

occurrence of algal blooms. Many natural events of this kind are strongly influenced by weather and hence climate.

2.3 Oceans and Seas

See Tables 2.7 and 2.8.

Sea temperatures: Globally, ocean temperatures have increased by about 0.8°C up to 2015, relative to the period 1971–2000. Increasing and thermal expansion of water is currently the main driver of the observed SLR. Observations of ocean temperatures are largely based on surface measurements from satellite observation systems and observations from research vessels and ships of opportunity.

Sea chemistry (pH and salinity): Globally, evidence is emerging that sea chemistry is changing in response to higher concentrations of CO_2 in the atmosphere and climate change. Marine biological systems have been shown to be very sensitive to changes in water chemistry. In Ireland, significant work has been done on the impacts of changes in chemistry on natural systems and growth.

SLR: Measurements in Ireland are based on the analysis of tide gauge systems. Isostatic uplift, i.e. geological rebound following deglaciation after the last Ice Age, distorts the signal, but has been accounted for in the analysis of SLR around Ireland. These sources are now complemented with data from satellite altimetry.

Waves and surges: Ocean waves are driven by local winds. Surges are the apparent rise in sea level as a result of distant storms at sea. Waves and surges impact on a wide variety of human activities, including coastal infrastructure, shipping, settlement and coastal erosion.

2.4 Cross-cutting Areas: Flooding (River and Coastal) and Soils

See Table 2.9.

Flooding: The pattern of human settlement in Ireland has been concentrated on urban development along the rivers and coasts with more than 50% of Ireland's population currently coastal in distribution, mainly in urban environments from small seaside towns to the main urban centres. Many areas of importance are already vulnerable to flooding. Climate change projections indicate increased risk of flooding. Many climate variables, such as precipitation and storms, and other parameters such as urban fabric and land use, increase this risk.

Soil: The condition and ecosystem function of soils is influenced by a wide variety of parameters including climate, land use and land management. Analysis of this cross-cutting issue requires development.

Table 2.7. Observed and projected changes for maritime variables for Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific Confidence projection
Sea surface temperature	Increases in Irish coastal water temperatures since 1980s. There has been an observed 0.85°C rise in Irish coastal sea since 1950, with 2007 being the warmest year in Irish coastal records The rate at which warming has occurred since 1994 (0.6°C per decade) is unprecedented in the 158-year observational record, the warmest years on record being 2005, 2006 and 2007 (Nolan *et al*., 2010) An increase of 1.02°C above the long-term mean (1982–2010) in inshore waters to the north of Ireland was recorded in 2015 (Larsen *et al*., 2016) Between 1982 and 2015, satellite composite data (Casal *et al*., 2017) from all waters surrounding Ireland show an overall increase of 0.26°C per decade (p-value ≤0.05)	High	Increased intensity of storms, ongoing increase in mean sea temperature	Medium
Sea chemistry (pH and salinity)	Increased seawater acidity observed in both surface waters and Labrador Sea Water (intermediate water mass) between 1990 and 2010 (McGrath *et al*., 2012); salinity changes vary with region. Atlantic waters freshened from 1960 to 1990 and are now becoming more saline. Associated changes in water mass formation/circulation. No distinct salinity trends exist in deeper waters on the Irish continental shelf (i.e. water depths of *c*. 200 m). Surface salinity anomalies on the Irish shelf also show variability from year to year, with evidence of freshening in coastal waters associated with increased winter rainfall (Nolan *et al*., 2010)	High for acidity, low for salinity	With increasing CO_2 in the atmosphere, the acidity is projected to increase; salinity changes vary with region. Changes in rainfall will affect coastal salinities, implications for coastal dynamics, water column stability, water quality, etc.	High for acidity, low for salinity
Sea phenology	The growth season in coastal waters has expanded for some phytoplankton species, primarily diatoms Warm water zooplankton species have shifted northwards in their distribution, with a decline of cold water species evident. In warm years, jellyfish and comb jellies are more evident with an increase since 1997 (Nolan *et al*., 2010). Many, but not all, warm water species, including sprat, anchovy, pilchard and blue-mouth, have increased in abundance to the north of Ireland and in the Celtic Sea The survival of salmon at sea has declined since the 1970s and the recruitment success of the European eel has dropped significantly since the 1980s (Nolan *et al*., 2010)	Medium/high	Changes will continue in the phenology of biological events and this will have a serious impact on the structure and function of marine ecosystems	Low

Table 2.8. Observed and projected changes for SLR in Ireland

Climate variable	Observed changes	Scientific confidence	Projected changes	Scientific confidence projection
SLR < 1 m	Since the early 1990s (1993) a SLR of *c*. 3.5 cm per decade (currently *c*. 3.4 mm/year) has been observed. Earlier tide gauge records pre-1990 show SLRs of 1–2 mm/year for Ireland's coasts. This forms a clear indication of the expected acceleration in SLR from warming of a coupled atmosphere–ocean system (Devoy, 2008)	Medium	Rise of *c*. 55–60 cm to 2100 [based on IPCC RCPs 2.6–4.5 and other medium-scale climate warming scenarios, namely Dunne *et al*. (2008) and Lowe *et al*. (2009)]. Predicted changes in mean sea level will be the primary driver in magnifying the impacts of changing storm surge and wave patterns in coastal areas	Medium/high
			Regional SLR, allowing for isostatic components, of *c*. 25 cm (Dublin/east coast of Ireland), *c*. 44 cm (Sligo/central western coasts) and *c*. 40 cm (south-west Ireland) by *c*. 2080–2100 (Devoy, 2008)	Medium
SLR > 1 m			SLR will continue beyond 2100, but with large uncertainty as to ultimate stabilised levels (Hansen, 2015)	Low/medium
Waves and surges	Observational records and reanalyses indicate an increase in significant wave heights of about 20 cm per decade since the 1950s in the North Atlantic (IPCC, 2013a)	Medium	Expected changes in wave heights are uncertain, but recent high-resolution simulations focused on Ireland (Gallagher *et al*., 2016) suggest a 15% decrease in mean and extreme significant wave heights by the end of the century (Gallagher *et al*., 2016)	Low
			Expected surge levels (i.e. temporary sea surface heights above the "background" sea level) for most non-estuary coasts for the 20- to 30-year return period surge events are likely to increase by ≤9mm/year up to 2100 (*c*. 9 cm rise) (Lowe *et al*., 2009)	Medium
			Increase in number of high-magnitude storms, generating bigger associated surges (> 1 m) by 2031–2060 (Devoy, 2008)	Low/medium

Table 2.9. Observed and projected changes for cross-cutting variables

Climate variable	Observed changes	Projected changes
River flooding	Linked to precipitation patterns	Increased risk of river flooding
Coastal flooding	Linked to storm patterns and SLR	Increased risk of coastal flooding, particularly as a result of the impacts of SLR and surge/storminess with coupled surge events. Losses in coastal wetlands: > *c*. 20% losses for medium-based change scenarios
Soil: inundation of poorly drained land	Linked to precipitation patterns	Increased duration of standing water on poorly drained lands in winter. Greater drying of turloughs and rain-fed lakes in summer
Soil: inundation of poorly drained land	N/A	Increased soil moisture may lead to enhanced N_2O emissions (Dong-Gill, 2013)

N/A, not available.

3 Sectoral Impacts and Adaptation Options

The information in this chapter is intended as a supplement for sectoral decision-makers tasked with developing climate change adaptation strategies and plans. The sectors chosen for this analysis have not been prioritised, but are generally understood as important to the Irish economy and society and are potentially vulnerable to climate change impacts.

The information provided is structured according to changes in key climate variables (as set out in Chapter 2), projected sectoral impacts and potential adaptation options as set out in the academic literature. Expert opinion is used to fill information gaps. The list is not exhaustive, as it is beyond the scope of this report to provide high-level detail. Where large knowledge gaps exist, these are identified as areas for future research, action or monitoring.

Some of these adaptation options will need to be considered in the short term and others will become more relevant as climate change progresses. All will need to be costed and investigated for their effectiveness as the adaptation process progresses and is co-ordinated at both sectoral and strategic level. This is beyond the scope of this analysis.

Given the considerable uncertainties that attach to projected changes, particularly as regards precipitation and extreme weather, it will be important that adaptation choices are robust, i.e. that they are relatively insensitive to uncertainty and aim to strengthen resilience at national, local and sectoral levels. Adaptation options, particularly soft and institutional measures, need to be flexible in order to respond to short-, medium- and long-term changes as they emerge. There are interdependencies between the impact of adaptation options in different sectors and their economic, social and environmental impacts and their resilience and capacity to recover from external shocks.

Consequently, there is much opportunity for the adoption of win–win policy measures, for example measures that can protect against climate change impacts such as flooding, but that also deliver other benefits for human health, protection of livelihoods, biodiversity, etc.

Ideally, adaptation should be co-ordinated between sectors and planned within an "adaptive risk management framework" that is responsive to new information and stakeholder feedback and becomes more detailed and quantified over time. Tables 3.1–3.11 provide numerous examples of individual adaptation options, but there is much scope for adaptation to be delivered through the use of "decision pathways", whereby ultimate goals are identified, but the route to adaptation is flexible to the emerging evidence on climate change with relevant pre-planned intermediate adaptation options being triggered as new climate thresholds are realised.

3.1 Critical Infrastructure and the Built Environment

Critical infrastructure represents those national infrastructure assets that are essential for the functioning of the country and the delivery/ maintenance of vital societal functions. It includes energy, transport, communication networks, water services and health services. Ireland's critical infrastructure could be at risk from projected changes in climate and, in particular, increasing temperatures, SLR, changing rainfall patterns and the increased occurrence of extreme weather events.

The built environment refers to the residential and commercial building infrastructure. Climate change is expected to have profound impacts on the built environment (Revi *et al*., 2014) as a result of changes in temperature, precipitation patterns, extreme events and SLR. Governments are key to crafting and co-ordinating building sector responses and can identify and encourage synergies between adapting buildings to climate change and mitigating their GHG emissions, recognising the potential for multiple benefits (Chalmers, 2014).

3.1.1 Conclusions

There is a general lack of information available on the vulnerability of Ireland's critical infrastructure to climate change. In particular, little is known about the status of infrastructure that is owned or managed by

Table 3.1. Climate change impacts on critical infrastructure and the built environment

Sector	Changes in climatic variables	Impacts	Adaptation options
Transport: road, rail, sea, aviation, ports	Temperature increases in summer and more intense heatwaves	Thermal expansion of roads and rail lines (EC, 2013), leading to degradation and disintegration	Assess vulnerability of infrastructure and design climate-resilient infrastructure (IAE, 2009)
		Impacts of heat on passenger comfort (especially for rail)	Improved carriage and vehicle design
	Decrease in cold snaps and frost and ice days and nights	May reduce minor accidents and reduce personal and motor insurance costs	Improved communication of travel conditions and timely advice (Collins *et al.*, 2011)
	SLR	Infrastructure located on low-lying coastal areas (e.g. rail lines on east coast, ports infrastructure on the east and south coasts, Shannon Airport)	New infrastructure managed and controlled to avoid areas susceptible to coastal flooding and erosion (IAE, 2009)
		Damage to infrastructure (all) and service disruption	New infrastructure designed to cope with changing weather patterns and extreme events
	Extreme events (flooding, winds)	Possible impact on road and rail embankment and verge stability	Improved design, monitoring and maintenance
		Changing patterns of siltation for ports	Improved design, monitoring and maintenance
Energy: supply and grid	Temperatures increase	More energy demands are possible for cooling (DECLG, 2012a) Water cooling of power stations, including cooling water availability (DECLG, 2012a)	Review of current and future energy demands (IAE, 2009)
	SLR	Infrastructure, power stations, storage facilities located on the coast that are vulnerable. Potential damage to offshore wave and tidal energy generation systems	Avoid development in high-risk areas such as flood plains, unless justifiable (National Directorate for Fire and Emergency Management, 2014) Enhance design criteria; update disaster preparedness (Revi *et al.*, 2014)
	Extreme events	Potential damage to power generation and infrastructure	Enhance design criteria; update disaster preparedness (Lyons *et al.*, 2013; Revi *et al.*, 2014)
	General wind characteristics	Wind generation will deliver at least 35% of electricity demand by 2020 and even more by 2030. Changes in wind regimes in Ireland will have a significant effect on electricity generation	Effective grid management; investment in diverse renewable energy generation and storage

Table 3.1. Continued

Sector	Changes in climatic variables	Impacts	Adaptation options
Built environmental/ construction	Temperature increases	Changes in energy demand (in both winter and summer, when demand for heating and cooling needs may change)	Enhance design criteria to meet changing energy demands (Chalmers, 2014)
	Changes in precipitation patterns	Vulnerability to groundwater contamination has implications for the location, performance and durability of building stock, waste water treatment and quality of groundwater (Sweeney *et al*., 2013)	Building materials must be designed and selected for future exposure conditions (Sweeney *et al*., 2013 In exposed zones, restrict permissions to sheltered areas (Sweeney *et al*., 2013)
	SLR	Implications for location, performance and durability of housing stock in low-lying, coastal or flood-prone areas (Sweeney *et al*., 2013)	Changes in planning regulations, changes in building design, materials, codes and standards (Revi *et al*., 2014)
	Extreme events (including wind-driven rain)	Implications for location, performance and durability of housing stock (Sweeney *et al*., 2013)	Buildings must be located in a way that avoids future exposure conditions (Sweeney *et al*., 2013) Insurance industry to encourage policyholders to cut risk exposure (Chalmers, 2014)

the state. This is a knowledge gap that needs to be addressed. Some information exists on the impacts of climate change on the built environment, but not enough is known about specific vulnerabilities or the roll-out of policy/actions in this area. In addition, this is an area that has large potential for emissions mitigation actions. As yet, we know little of how the twin objectives of adaptation and mitigation might be achieved with a view to achieving synergies and avoiding maladaptation in this sector.

3.2 Industry and Insurance

The impact of climate change on economic development and growth potentially affects all economic sectors (Arent *et al*., 2014); this includes direct impacts and secondary impacts due to market links and supply chains. Climate change will also affect insurance systems. More frequent and/or intensive weather disasters as projected for some regions/hazards will increase losses and loss variability in various regions and will challenge insurance systems to offer affordable coverage (Arent *et al*., 2014).

While not all business sectors will be equally impacted, climate change will impact on Irish businesses through changing markets, impacts on premises and processes, and increased vulnerability of supply chains, which may have implications for investments, insurance costs and stakeholder reputation (Forfás, 2010).

Industries, such as pharmaceuticals, software, information and communication technology (ICT), food and refrigeration, could be impacted directly under future climate conditions from shortage of water in the summer and extreme precipitation in winter. In addition, the supporting infrastructure (transport, communications, energy) that such industries depend on could also be impacted, leading to indirect impacts on industry such as loss of productivity and disruption of supply chains (McDermott, 2016).

3.2.1 Conclusions

There is a general lack of information available on the vulnerability of Ireland’s industry and business to climate change. This is a knowledge gap that needs

Table 3.2. Climate change impacts on industry and insurance

Sector	Changes in climate variables	Impacts	Adaptation options
Industry	Extreme events	Food, drinks and construction industries impacted (Forfás, 2010)	Planning authorities to evaluate need for further legislative restrictions on new builds in risk areas (Forfás, 2010)
		Reduced productivity due to compromised supporting infrastructures such as road, rail and communications (Environment, Community and Local Government, 2012a) Many chemical and pharmaceutical industries are based on the coast, which may be prone to flooding and SLR (Forfás, 2010).	Climate change incorporated into long-term planning, design, investment and maintenance of all actors in the transport sector (Forfás, 2014)
	Temperature increases	Impacts on ICT due to cooling requirements (Forfás, 2010) ICT/pharmaceuticals: rising ambient air temperatures, variations in water quality and availability of cooling water can have effects on chemical processes (Forfás, 2010) Heatwaves could damage industrial plants and materials; storms may damage larger industrial infrastructure and mobile machinery	The establishment of district cooling should be actively considered (Forfás, 2010) Changes in long-term planning, standards and building regulations, use of new building materials
	Changes in precipitation patterns	Impacts on water resources; significant for pharmaceuticals, ICT, food and drinks (Forfás, 2010)	
Insurance	Extreme events	Financial services impacted by domestic and global extreme events	Need a knowledge base of the potential insurance implications of climate change for business
		Insurance sector sensitive to weather and climate risks and to limits in capacity of global financial markets to absorb risk, in particular reinsurance capacity (Forfás, 2010)	Irish Insurance Federation could develop risk assessments for business insurance (Forfás, 2010; Surminski, 2015)
		Increased risk of industrial contamination of water systems due to flooding	Enhanced protection systems mandated under operating licences

to be addressed in collaboration with industry itself. It is also worth noting that there may be opportunities for some segments of industry such as those in the climate services sectors, data centres, water infrastructure management, but these remain to be quantified.

3.3 Agriculture

Agriculture is one of Ireland's most important indigenous sectors and accounts for approximately 64% of the total land area of Ireland. Approximately 80% of the agricultural area is devoted to grass (silage, hay and pasture), 11% is devoted to rough grazing and the remainder is allocated to crop production. Beef and milk production currently account for around 58% of agricultural output.

According to the agricultural accounts from the Statistical Yearbook of Ireland 2014 (2014a), livestock, milk and crops (in million euros) were worth €3,158.7, €2,073.5 and €1,963.2, respectively, and roughly 90,000 people were employed in agriculture during 2013.

The effects of climate change on crop and food production are already evident in several regions of the world, with negative impacts more common than positive (Cameron, 2014). For Ireland and northern Europe more generally, the impacts of climate change are not expected to be as severe as those projected for areas in the southern parts of Europe, where the

Table 3.3. Climate change impacts on agriculture

Sector	Changes in climate variables	Impacts	Adaptation options
Dairy	Temperature increases	Extension of growing season by over 35 days per year (Nolan, 2015) Extended grazing season (Hennessy, 2010) All-year growth in coastal and sheltered areas	Adoption of earlier planting and harvesting
		Possible increase in viruses and diseases, e.g. foot-and-mouth disease, bluetongue viruses in cattle and sheep and aphids in winter crops (Flood, 2013) Extended viability of disease vectors throughout the year	Introduce and/or increase vaccination and disease control
	Changes in precipitation patterns	Changes in soil moisture (increases and decreases) will impact on plant/crop growth Impacts on soil carbon stores and sequestration potential	Modification of animals' diets Increased need to cultivate drought- and heat-resistant crops
	Extreme events (heatwaves): mid-century projections indicate the warmest 5% of daily maximum summer temperatures are projected to increase by up to 2.6°C (Nolan, 2015)	More frequent and intense heatwaves may put water stress on both animals and plants (Flood, 2013)	Protection from the elements. Improved availability of water and shade
	CO_2 concentration	Improved net biomass production (possible lower nutrient value). There remains significant uncertainty as to the regional impact on crops and grass	Ongoing review of plant species
Tillage	Temperature increase	Increased Irish agricultural production, as global agriculture is under stress (Schulte and Lanigan, 2011)	Protection from the elements
		Projections for future crop and grass production showed a decrease of up to 9% in cereal crops, an increase in maize of up to 43–97% and an increase in grass production of up to 49–56% (Shrestha *et al*., 2015)	Adoption of earlier planting and harvesting
	Changes in precipitation patterns	Nutrient leaching, soil erosion and pollution may result (higher risk from winter precipitation?)	Increased drainage to compensate for winter precipitation. Possible negative impact of carbon stocks in soils
	Heavy rainfall	Water stress in summers Impeded land access due to heavy winter precipitation Water contamination during flooding/heavy rainfall (Flood, 2013)	Recognise and account for the variability of soils and their capacity to deliver on different soil functions and ensure that land is managed in such a way that the total suite of soil functions is maximised (Schulte *et al*., 2014)
	Drier summers with episodic heavy rainfall events	May cause enhanced N_2O emission events (Leahy, 2004)	Nutrient management plans should include options to respond to meteorological conditions (Abdalla, 2010)
	Extreme events (cold events, wet winters and springs)	Impact of multiple extreme climate events (e.g. fodder crisis of 2013)	Modification of fodder crops for animal diet
		Reduction in cold snaps and frost days will impact pest die-off and subsequent plant health (Flood, 2013)	Protection from the elements
		Maladaptation to reduction in frequency of cold events (e.g. poor response to snow events in 2011 and 2012)	Reduced need to cultivate frost-resistant crops

Table 3.3. Continued

Sector	Changes in climate variables	Impacts	Adaptation options
Tillage	CO_2 concentration: observed decrease in nutrient and protein in C3 and to a lesser extent in C4 crops in high CO_2 growing conditions (Myers *et al*., 2014)	Enhanced net biomass production (possible lower nutrient value)	
Horticulture	Temperature increases (air and soil)	Changes in the risk of pests and diseases (Flood, 2013) High temperatures and water stresses may turn carbon sinks into carbon sources (Schulte and Lanigan, 2011)	Pest control
	Changes in precipitation patterns	Large volume of research links to nutrient leaching	Water harvesting (investment in local storage) in the winter
		Less rainfall in the summer and increased winter rainfall increase nitrate leaching and impact water quality (IPCC, 2014b)	Implementing water management strategies (Flood, 2013)
		Aridity is projected to increase by 40%–120% from 2020 to 2080. Possible increase in irrigation requirement (Flood, 2013)	Adjusting herd size in certain regions Growing crops such as maize instead of potatoes Implication for the total abatement of extended grazing (Schulte and Lanigan, 2011)
		Increase in water demand for spray irrigation of 15% in 2020 up to 45% in 2080 under the medium-emission scenario and 36% in 2020 up to 58% in 2080 under the high-emission scenario (Flood, 2013)	Explore potential to exploit the variability of soil and capacity to deliver on different soil functions (Schulte *et al*., 2014)
	Extreme events (storms, cold events, heatwaves)	Impact of multiple extreme climate events (e.g. fodder crisis of 2013) Reduction in cold snaps and frost days will impact pest die-off and subsequent plant health (Flood, 2013)	Some crop and fruit species may need to be adapted to avoid adverse impact of lack of frost, which triggers phenological phases (Donnelly, 2013)
		More frequent and intense heatwaves may put water stress on both animals and plants (Flood, 2013) Lowland livestock may benefit from less exposure to harsh conditions	May increase the need for irrigation in certain parts of the country

overall expected decrease in precipitation and water availability is far greater (EEA, 2012). Nonetheless, all aspects of agriculture in Ireland will be affected by climate change, and the main impacts of climate change will probably result from changes in air and soil temperature, precipitation patterns and extreme events. In addition, the impact of multiple events or a sequence of events may combine to produce “perfect storm” scenarios, which will challenge resilience to otherwise typical weather patterns.

In general, grass-based dairy systems have the capacity to adapt to projected climate change (Fitzgerald, 2009); however, there are specific challenges that will need to be addressed. Increasing the resilience of grass-based systems may constrain the level of intensification (Courtney, 2013).

Given the importance of food and other crops, a large volume of international, regional and national research has been undertaken to understand the potential response of key crops to environmental changes including climate change and increased CO_2 concentration.

3.3.1 Conclusions

More information is needed on the impacts of climate change on agricultural land, water stress, soil quality, crops, pests, pathogens and invasive species. Some impacts, such as invasive species and pathogens, are already on monitoring schedules, which should be continued within the context of a changing climate.

3.4 Forestry

The 731,650 hectares of forest in Ireland in 2012 represents 10.5% of the total land area of Ireland. Since 1990, approximately 300,000 hectares of land has been afforested under various national forest programmes. The national net uptake of these forests – the forest sink – is currently in the region of 4.8 million tonnes of CO_2 equivalent per annum. Depending on carbon sequestration accounting rules, carbon uptake in forests planted since 1990 is forecast to reach an average of 4.4 million tonnes of CO_2 equivalent per annum in the decade from 2021 to 2030.

The number of people employed in forestry in 2013 was just under 12,000 (O'Driscoll, 2014). According to the Forest Service's *Ireland's Forests – Annual Statistics* (2014), the direct economic activity value of forestry in Ireland is €386.9 million. Processing adds an additional €1.389 billion to the direct output value of the sector.

The management of forestry is a long-term process and forests in Ireland are generally worked on rotation periods (between planting and final harvest) of 40–50 years. Within this timeframe, climate change is projected to have a significant impact and, as a result, introducing and/or adapting management practices that strengthen the ability of forests to withstand the impacts of climate change will be critical (Ray *et al*., 2009).

The long planning period associated with forest management means it may be appropriate to consider

Table 3.4. Climate change impacts on forestry

Sector	Changes in climate variables	Impacts	Adaptation options
Forestry	Temperature	Exotic pests and pathogens introduced to Ireland (Schulte and Lanigan, 2011). Root and butt rot fungi such as *Fomes* may be a greater threat in warmer climates (Black *et al*., 2010). Over 50% of the species investigated showed significant changes to the timing of leaf unfolding and leaf fall (Black *et al*., 2010)	Pest control Improved monitoring and enforcement systems for pest control, e.g. the response to *Chalara fraxinea*, which causes ash dieback Diversity in national forest; employ currently unrepresented species (Hendrick *et al*., 2008)
	CO_2 concentrations	Timber quality may be affected by rapid growth as a result of increased CO_2 emissions (Environment, Community and Local Government, 2012a)	Diversification of biomass market to create competitive income streams for multiple grades of biomass product
	Precipitation	Reduced summer rainfall may lead to loss of productivity (Schulte and Lanigan, 2011); however, there is also evidence of forest growth being limited by current access to water (Saunders *et al*., 2014) Soil moisture in general could become an increasingly relevant issue for this sector	Consider alternatives to drought-sensitive species (Wheelan, 2014) Matching the location of forest species to locations will allow appropriate land use (Schulte and Lanigan, 2011)
	Extreme events (storms, extended dry periods)	Reduction in cold snaps will allow certain tree species such as oak and ash (Forestry Focus, n.d.) to grow better but will be detrimental to those requiring frost	Matching the location of forest species to locations will allow appropriate land use (Schulte and Lanigan, 2011)
	Extended dry periods are expected to increase by 7–28% annually under the medium–low scenario (Nolan, 2015)	Frequent strong winds may affect timber supply (Schulte *et al*., 2011), in particular blowdown in exposed sites Increased occurrence of droughts can affect tree growth and survival	

a wider range of potential climate scenarios when looking to address climate change impacts on the forestry sector. Forest managers must plan with the expectation that both weather events (storms, cold snaps, heatwaves) and at least one 20-year event will impact on their stand in the management cycle.

3.4.1 Conclusions

While a good evidence base exists for the forestry sector, a watching brief and good monitoring regimes will have to be kept on the impacts of new invasive species, pests and pathogens, changes in soil moisture regimes and forest blowdown in exposed sites.

Table 3.5. Climate change impacts on terrestrial biodiversity

Sector	Changes in climate variables	Impacts	Adaptation options
Terrestrial biodiversity	Temperature increases	Species will move to higher latitudes and altitudes (Coll *et al*., 2013) Change in phenology of native species (Gleeson *et al*., 2013) Rate of climate change may exceed the adaptive capacity of some species (IPCC, 2014b) Degraded raised bogs are predicted to have substantial losses in the southern edge of the distribution (Coll *et al*., 2013)	Creation of green infrastructure and maintenance and promotion of connectivity of wider landscapes to ensure that species can reach new climate spaces (Coll *et al*., 2013)
	Changes in precipitation patterns	Flora and fauna will respond differently to changes in precipitation; in general, temperate climate species will be adversely impacted by more intense hydrological cycles	
	Extreme events	Destruction of species or habitats (Department of Arts, Heritage and the Gaeltacht, 2011)	Creation of farmland habitats to support named species (Finn *et al*., 2010) Strategic national policies to maintain healthy ecosystems Establish more diverse agro-forestry systems
	SLR	Destruction of coastal habitats (Coll *et al*., 2013)	Coastal defences deployment for key infrastructures and sites of high nature or heritage value
		SLR combines with storm surges to accelerate erosion of vulnerable coastal and estuarine habitats and ecosystems	Managed retreat (abandonment)
	Cumulative effects	Threatened habitats will be further endangered (Department of Arts, Heritage and the Gaeltacht, 2011)	Strategic national policies to maintain healthy ecosystems
		The terrestrial habitats most vulnerable to climate change are: • upland habitats (siliceous and calcareous scree, siliceous and calcareous rocky slopes, alpine and subalpine heath); • peatlands (raised bog, blanket bog); • coastal habitats [fixed dunes – combined with additional threat of SLR to coastal habitats (Coll *et al*., 2013)] Endangered native species (Department of Arts, Heritage and the Gaeltacht, 2011) Invasive species (Maguire *et al*., 2011), expansion in range of foothold species (Maguire *et al*., 2011)	Establish more diverse agro-forestry systems

3.5 Terrestrial Biodiversity

The impacts of climate change are being observed across all continents and oceans (IPCC, 2013b). Nationally, impacts are being felt on freshwater resources, natural carbon stores, marine ecosystems, wildlife and habitats, and biodiversity.

In addition to its intrinsic value, biodiversity provides a wide range of ecosystem services that are essential for using the Earth's resources sustainably that include:

- provisioning services: harvestable products such as food, drinking water and raw materials;
- regulatory services: water treatment or slowing the passage of water;
- cultural services: services directly involving people, e.g. recreation;
- habitat or supporting services: services needed to maintain others, e.g. pollination, that include genetic diversity and maintenance of life cycles (EEA, 2010).

The ecosystems services in Ireland are estimated to be worth €2.6 billion per annum (Bullock *et al*. 2008). Throughout Europe, including Ireland, the rate of habitat degradation and ensuing biodiversity loss is accelerating (EEA, 2010) and it is in this context that the threats and opportunities posed by climate change must be considered.

3.5.1 Conclusions

Some information is available nationally on terrestrial habitats and biodiversity. Observed impacts should be monitored with a view to conducting further research in the context of a changing climate. More information is required on the impacts of climate change on ecosystem services and on the role that biodiversity and habitats play in both mitigating and adapting to climate change. For example, protecting biodiversity can help limit GHG concentrations because forest, peatlands and other habitats are major stores of carbon. Moreover, healthy ecosystems, e.g. coastal wetlands, can be employed to buffer against coastal erosion. Therefore, ecosystem approaches should be an integral part of the overall mitigation and adaptation effort.

3.6 Peatlands and Fens

Peat is the remains of plant and animal constituents that accumulated under more or less water-saturated conditions owing to incomplete decomposition (Rydin and Jeglum, 2006). Soil scientists in Ireland have defined peat as consisting of at least 30% (dry mass) dead organic material. Peatlands are ecosystems with a surface layer of peat at least 30 cm (on drained land) or 45 cm (on undrained land) thick, but it is often much thicker (Renou-Wilson *et al*., 2011). Peat soils cover an estimated 20% of the national land area, storing ~75% of the national soil carbon. Much of this area has been extensively modified by humans over centuries and currently more than 40% of the peatlands do not have the original hydrophytic vegetation, which has been replaced by trees or grass or removed altogether for peat extraction for energy or domestic use (Wilson *et al*., 2013).

Undisturbed peatlands provide important global and regional ecosystem services: carbon storage, water storage and biodiversity, as well as spiritual, cultural and educational services. The societal benefits of Irish peatlands are based on ecosystem functions that are inherent to peatlands and are tightly interlinked. These functions can be substantially influenced by human activities, as well as by climate change and climate extremes, thereby directly influencing the benefits that this natural resource can provide.

Many peatlands, and particularly raised bogs, may be adversely impacted given that the habitats are already in decline and their resilience may be weakened by ecosystem fragmentation and historical degradation. The variation in the summer water table is the most significant factor for these bogs, which are most probably degraded around the edges. Large variations in water table in the summer time have been reported already in restored sites in the Midlands. Their small geographical "range" also puts them at risk, given the climate change predictions in Ireland.

There are strong co-benefits with respect to mitigation of GHG emissions associated with appropriate management of peatlands and fens, as a result of the high potential losses of stored carbon to the atmosphere.

Table 3.6. Climate change impacts on peatlands

Sector	Changes in climatic variable	Impacts	Adaptation options
Peatlands	Temperature	Northern species such as *Saxifraga nivalis* will probably lose a significant part of their distribution as a result of temperature increase (Malone and O'Connell, 2009) Changing vegetation patterns (Renou-Wilson *et al*., 2011) Possible extension of bog species including mosses and bog myrtle (Malone and O'Connell, 2009) Inability to adapt quickly may threaten many species in peatlands (Malone and O'Connell, 2009) Invasive species out-compete native vegetation leading to destabilisation of ecosystems (Malone and O'Connell, 2009)	Fully protect all the remaining raised bog habitats that are near intact or degraded but still capable of natural regeneration (Renou-Wilson *et al*., 2011) Maintenance and conservation of wetlands (IPCC, 2013b)
	Precipitation	Areas most affected will be those that have the most changes in both precipitation and temperature such as the basin peat of the Midlands (Renou-Wilson *et al*., 2011)	Reducing the vulnerability of peatlands by a substantial programme of drainage, blocking and wetting or re-wetting (Renou-Wilson *et al*., 2011)
	Projections indicate an increase in the number of very wet days (> 30 mm) of ~24% under the high-emission scenario by mid-century (Nolan, 2015)	A severe diminution of Irish peatland cover by 2075 (Renou-Wilson *et al*., 2011)	Maintenance and conservation of wetlands (IPCC, 2013b)
		Increased precipitation could lead to more optimal conditions for carbon sequestration, but intense rainfall could enhance peatland erosion in susceptible areas (Renou-Wilson *et al*., 2011) Long periods of low precipitation may increase the risk of bog fires, especially in drained and degraded peatlands	Restoration of peatlands (Renou-Wilson *et al*., 2011)
Peatland and fen	Combined climate factors	Projected loss of climate space at the southern edge of the distribution is indicated for degraded raised bogs (Coll *et al*., 2014) The projected available climate space for active blanket bog is regionally sensitive to loss, notably for lower lying areas in the south and west (Coll *et al*., 2014)	Uncertain

3.6.1 Conclusions

The potential impact of climate change on Ireland's peatlands and fens remain highly uncertain. This derives from the combined uncertainty in the projection of climate change itself and, specifically, the uncertainty in precipitation, which is a main driver of ecosystem response, and lack of knowledge on the current vulnerability status of much of Ireland's wetlands, peatlands and fens.

3.7 Coastal Areas

Coastal flooding and erosion pose serious threats to Ireland's economy, society and natural environment and this is particularly the case as Ireland's major cities (Dublin, Cork, Limerick and Galway) are located on the coast. Coastal flooding occurs when high tides, surges and wave-overtopping combine to inundate coastal areas. Coastal erosion, which is intimately linked with coastal flooding, occurs when the sea progressively encroaches on the land.

Climate change will impact on and offer opportunities to all sectors operating in coastal areas and these include agriculture, biodiversity, marine and fisheries, critical infrastructure and tourism. Engineering solutions to emerging climate impacts may not always be desirable or practicable. Soft solutions, such as planned retreat, may be the preferred option.

Table 3.7. Climate change impacts on coastal areas

Sector	Changes in climatic variable	Impacts	Adaptation options
Coastal	SLR	350 km² and 600 km² is vulnerable if the sea level rises by 1 m and 3 m, respectively (Flood and Sweeney, 2012) Coastal wetlands, floodplains and estuaries at risk from saltwater inundation (DECLG, 2012a) Groundwater may be at risk from saltwater. This is problematic, as, with projected decreases in summer rainfall, Ireland may become increasingly reliant on groundwaters for its water supply	Because of the current fragmented approach to planning and decision-making in coastal areas, adaptation in the coastal zone might be facilitated by taking a strategic approach to planning (e.g. ICZM), incorporating a cross-sector perspective and taking into account both the terrestrial and marine components of the coastal zone (O'Dwyer, 2017)
	Extreme weather	Coastal damage to promenades and sea defences due to storms (National Directorate for Fire and Emergency Management, 2014) Tidal flooding (National Directorate for Fire and Emergency Management, 2014) Risk of death, injury, ill health or disrupted livelihoods (IPCC, 2014b)	On account of the current fragmented approach to planning and decision-making in coastal areas, adaptation in the coastal zone might be facilitated by taking a strategic approach to planning (e.g. ICZM), incorporating a cross-sector perspective and taking into account both the terrestrial and marine components of the coastal zone (O'Dwyer, 2017)
	Sea surface temperature	Projected increases in sea surface temperatures are expected to increase the intensity of cyclones, which will result in more extreme storm activity with the potential to bring the devastation of storm surges to the coast of Ireland (Wang *et al.*, 2008; Nolan, 2015)	As a result of the current fragmented approach to planning and decision-making in coastal areas, adaptation in the coastal zone might be facilitated by taking a strategic approach to planning (e.g. ICZM), incorporating a cross-sector perspective and taking into account both the terrestrial and marine components of the coastal zone (O'Dwyer, 2017)

ICZM, integrated coastal zone management.

3.7.1 Conclusions

Some good information exists for this sector; however, more information is required regarding SLR at the national level. More information is required on the vulnerability of low-lying coastal urban centres and critical infrastructure to the impacts of climate change. Integrated Coastal Zone Management is required and needs to be implemented to coherently meet the challenges posed by climate change.

3.8 Marine and Fisheries

The marine and fisheries sector is a very important industry in Ireland. The seafood industry, according to the Irish Sea Fisheries Board, is worth €700 million. In 2013, the fisheries sector supported just under 11,000 jobs and the value of fish landed by Irish vessels in home ports in the same year was €212 million (DAFM, 2015).

Ireland's marine sector and its infrastructure will be at risk from climate change through increasing sea level, coastal flooding and erosion and through physico-chemical changes to the marine environment.

Ireland's marine ecosystems (i.e. offshore, inshore and coastal) are home to a rich and diverse range of species and habitats and our oceans are a national asset supporting an important and diverse marine economy. In addition, our marine resources also provide non-commercial benefits, such as amenity and biodiversity, as well as important ecosystem services, such as carbon sequestration and nutrient dispersal.

A changing climate has wide-ranging implications for Ireland's marine environment and these changes are already having, and will continue to have, significant impacts on both the fisheries and aquaculture industries as the effects of climate change are further realised. Understanding the effects of climate change on marine ecosystems remains a challenge, but the

Table 3.8. Climate change impact on fisheries and marine

Sector	Changes in climatic variable	Impacts	Adaptation options
Fisheries	Sea temperature and depth-averaged temperature is expected to increase by 0.89°C and 1.79°C by 2090 (Olbert *et al*., 2012)	Warming is expected to push fish stock northwards and possibly reduce abundances of current commercial fish (Nolan *et al*., 2010) Increasing water temperature may have a negative impact on aquaculture (Nolan *et al*., 2009) Warmer water will aid algal blooms causing nutrient run-off and eutrophic conditions Warmer waters may promote new types of bacteria and pathogenic viruses, which can threaten fish and shellfish populations	Diversification of species Establish a dedicated research programme to monitor climate change in Irish waters (O'Dowd *et al*., 2011)
	Ocean chemistry (acidity, salinity, etc.)	Could affect the food web in Irish waters, such as primary producers, cold water coral reefs, shellfish and crustaceans (O'Dowd *et al*., 2011)	Establish a dedicated research programme to monitor climate change in Irish waters (O'Dowd *et al*., 2011)
	Extreme weather	Heavy precipitation may lead to increased influx to fluvial systems, including increased contamination	
Marine infrastructure	SLR Extreme events (storms, surges)	Coastal infrastructure (e.g. ports, marinas, etc.) will be impacted Those working in maritime transport, commercial fisheries and offshore enterprises will be at risk	Nationally, a major knowledge gap exists in relation to the risks of climate change in this sector and the possibility of adaptation actions
Tidal/ocean/offshore wind energy	SLR	Impact on location and operation of tidal, ocean/offshore energy infrastructure	Technology is in rapid development; difficult to assess the vulnerability to these conditions; strong need to be aware of the impact of climate change (and CO_2 concentration) on the parameters controlling infrastructure performance and longevity
	Extreme weather	Increased storminess and windiness will put maritime transport and offshore energy infrastructure at risk (Boelens *et al*., 2005)	Engineering more resilient infrastructure
	Ocean chemistry	Potential impacts on infrastructure	

three major effects of climate change identified for Ireland's marine sector are increased sea surface temperatures, oxygen depletion and acidification.

3.8.1 Conclusions

There is a general lack of information on the vulnerability of Irish marine and fisheries sectors to the impact of climate change. As a number of other sectors interact here (e.g. coastal, critical infrastructure), it is important that a cross-sectoral risk-based assessment of this economically relevant sector is undertaken.

3.9 Tourism

The tourism industry is an economically valuable sector to many countries, including Ireland. The country's rich historical and cultural heritage sites, developed coastal areas and relatively unspoilt environment draws a lot of tourists to Ireland. The Department of Transport, Tourism and Sport estimated that in 2013 the revenue from tourism was €5.7 billion. While a lot of the infrastructure and facilities are potentially threatened by a changing climate, there are many opportunities within Irish tourism too, especially as other countries become too warm. There is also

Table 3.9. Climate change impacts on tourism

Sector	Changes in climatic variable	Impacts	Adaptation options
Tourism	Temperature	Lengthening of the tourist season (Forfás, 2010; Salmon, 2013) Diversification of tourist activities, particularly water-based sport (Forfás, 2010)	Respite tourist opportunities [heat refugees from severe heat in other parts of Europe (e.g. the 2015 heatwaves)]
	Precipitation	There may be greater demand for winter breaks abroad	Product diversification and innovation (Kelly and Stack, 2009)
	Extreme weather	Prolonged heatwaves and droughts may put stress on water supply and tourism products (Forfás, 2010) Storm surges, floods and increased wave heights may damage tourist and heritage sites depending on location (Forfás, 2010)	Consider the heritage officer model to address local climate change (Desmond and Shine, 2012) ICZM can provide a co-ordinated way of coastal management (Kelly and Stack, 2009) Develop tourism infrastructure that is sustainable and climate proof (Kelly and Stack, 2009)

ICZM, Integrated Coastal Zone Management.

the possibility of extending the tourist season into the shoulder periods of April/May and October, which would be a major boost to the industry and the Irish economy in general (Salmon, 2013).

3.9.1 Conclusions

Climate change will impact on tourism in Ireland in a number of both positive and negative ways. While some work has been undertaken, more information is needed in relation to the vulnerability of built heritage and coastal heritage sites, which should at least be put on a watching brief.

3.10 Water Management and Resources

Water management and resources are a part of Ireland's critical infrastructure. Water services cost over €1.2 billion to run in 2010, of which operational costs amounted to some €715 million, with capital expenditure of €500 million (DECLG, 2012b). The potential impacts of climate change on both water sources and infrastructure are recognised in Irish Water's *Draft Water Services Strategic Plan* (2015).

For Ireland, climate change will serve to exacerbate existing risks for water management and the projected areas of concern relate primarily to water supply, quality and flood risk. Climate projections indicate that water resources will become depleted in terms of both water supply and quality and this is against a background of increasing demand due to, among other things, increased irrigation requirements (Steel-Dunne, *et al*, 2014).

3.10.1 Conclusions

There is a general lack of knowledge on the vulnerability of national water resources and infrastructure to a changing climate. This multi-faceted problem must be able to account for high and low flows, an ageing water infrastructure and increased demand due to population increases.

3.11 Human Health and Well-being

Human health is intricately linked to climate and weather. Globally, there has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming. Throughout the 21st century, climate change is expected to lead to increases in ill health in many regions (IPCC, 2014a).

In Europe, the impacts of climate change on human health and well-being include flooding, extreme temperatures, air pollution, vector-borne disease and water- and food-borne diseases. These impacts are projected to change in the future; for example, where precipitation or extreme flooding is projected to increase in Europe, the risk of campylobacteriosis and cryptosporidiosis could increase (EEA, 2012).

Climate change is likely to alter risks to public health and well-being in Ireland. The key climate change-related exposures of importance to human health

Table 3.10. Climate change impacts on water management and resources

Sector	Changes in climatic variable	Impacts	Adaptation options
Water resources	Temperature	Increased water temperature leading to increased viability of pathogens.	Increased monitoring of water resources (Desmond and Shine, 2012)
	Precipitation	Decrease in water supply in summer (DECLG, 2012a) Increase in water resources during winter months, impacting on infrastructure	Incentives and regulations to manage demand are required (Desmond and Shine, 2012)
	Extreme weather	Frequency of flooding will increase, as will the intensity and areas of flooding (Murphy and Carlton, 2007). This will mean that areas previously not subject to flooding will be at risk Flood water contamination of water supplies (DECLG, 2012a)	Adaptation policies and actions, which should provide for flexible, "no regrets" strategies and measures that can be adapted to ongoing change through a managed adaptive approach (Hall *et al*., 2012)
Water infrastructure	Temperature	Increased water temperature leading to increased viability of pathogens Greater frequencies of drought	Need for increased treatment of wastewater prior to its discharge (Irish Water, 2015)
	Decrease in frost days	Decreased frost days and cold days, reduced risk of burst pipes and associated water leakage (damage), but may also make pipes more fragile	Development of a national framework and the introduction of a single national water authority with responsibility for system planning, delivery and maintenance (Desmond and Shine, 2012)
	Precipitation	Stress on the water grid during summer (DECLG, 2012a)	Incentives and regulations to manage demand are required (Desmond and Shine, 2012)
		Risks to groundwater quality from septic tank systems in the context of climate change (particularly increased precipitation) (Sweeney *et al*., 2013)	Dwellings should be connected to mains sewerage where practicable The groundwater monitoring network for quality and levels should be extended to cover aquifers anticipated to become vulnerable as a result of climate change (Sweeney *et al*., 2013)
	Extreme weather	Flood water contamination of water treatment plants (DECLG, 2012a) Impacts of flooding on "legacy septic tanks" (i.e. constructured under SR6: 1991 legislation, before the EPA's *Manual on Treatment Systems for Single Houses* (2000) and *Code of Practice* (2009) came into force	Amendment of legislation for wastewater management and monitoring (Desmond and Shine, 2012)

are likely to be increases in heatwave-related health impacts, decreases in cold-related health impacts, increases in flood-related health impacts, changes in patterns of food-borne disease, an increase in the burden of water-borne disease and an increase in the frequency of respiratory diseases due to changes in pollen and pollutant distributions (temporal and spatial) (Cullen, 2008; Pascal, 2013).

3.11.1 Conclusions

There is a general lack of information on a number of topics in this area including impacts on air quality, vector-borne pathogens, food-borne diseases, well-being and mental stress. This is a knowledge gap that needs to be addressed.

Table 3.11. Climate change impacts on human health and well-being

Sector	Changes in climatic variable	Impacts	Adaptation options
Health	Temperature	A 1°C increase above 15°C in the mean temperature was associated with a 1.5% and 1.6% increase in total mortality in rural and urban areas, respectively (Pascal, 2011) Rising temperatures in summer are likely to increase heat-related mortalities and morbidity (DECLG, 2012) Higher temperatures pose risks to health from changes in air quality (UK CCRA, 2016)	Co-ordinate the approach of the health sector in assessing and preparing for climate change impacts (Desmond and Shine, 2012) Public education on appropriate actions during warm weather There is little national research on this topic
	Temperature: coldest night-time temperatures are projected to increase by 1.4°C in the south-west of Ireland and by up to 3.1°C in the north under the high-emission scenario	While cold-related mortalities may decrease on account of increasing winter temperatures (DECLG, 2012), there is a risk of loss of societal learning/knowledge as to the appropriate responses to cold weather	Public awareness and educational programmes
	Temperature: warmer conditions (also combined with wetter conditions)	Food-borne diseases are likely to increase (DECLG, 2012) as a result of enhanced environmental conditions for bacterial growth and viral survival and inadequate food safety practices	Public education on diseases and ways to prevent and combat them should be given Reviewing and monitoring food safety standards (Elliot, 2014)
		Although not necessarily caused by climate change, several vector-borne diseases (i.e. diseases spread by insects and ticks) have emerged and expanded in Europe in recent years. These include *Plasmodium vivax* malaria, West Nile fever, dengue fever, Chikungunya fever, leishmaniasis, Lyme disease (already present in the UK) and tick-borne encephalitis (UK CCRA, 2016)	There is very little national-level knowledge or research in this potentially emerging area
	Phenology: pollen and other biogenic allergens	Budburst for birch has been observed to have advanced approximately 26 days over the period 1954–2000 (Fitter and Fitter, 2002). The projected budburst for birch is that it will take place earlier by 2100, which has implications for the birch allergy season (Caffarra *et al.*, 2013b)	Public education on warning systems and education on ways to prevent and alleviate symptoms
	Precipitation: the number of very wet days could increase annually by 24% under the high-emission scenario (Nolan, 2015)	Increase in rainfall and flooding may cause more water-borne disease from contamination of drinking water and inadequate cleaning practices (DECLG, 2012)	Practical advice and assistance should be provided to those affected, particularly to those most vulnerable, including those living in homeless shelters Evaluate the microbiological quality of water used for washing and irrigation (Elliot, 2014)
	Extreme weather	Heatwave events and warmer, drier summers are likely to invite more people to sunbathe, probably leading to more cases of skin cancer (DECLG, 2012)	Education with respect to appropriate behaviour and prevention measures should be taken, particularly with respect to identified vulnerable groups and facilities
	Extended dry periods are likely to increase by 12–40% during mid-century summer months, under both the medium- to low- and high-emission scenarios (Nolan, 2015)	Flooding may also give rise to increased cases of infectious diseases (DECLG, 2012)	
	Heavy precipitation: the annual number of very wet days (> 30 mm) is projected to increase by ~24% under the high-emission scenario by mid-century (Nolan, 2015)	Some potential to affect mental health (Berry *et al.*, 2010)	The public should be warned and advice about safety should be provided

4 Conclusions and Recommendations

4.1 Conclusions

This report provides a summary of the current state of knowledge of the impacts of current and future climate change in Ireland across a number of key environmental, economic and social sectors. It represents the distillation of a large body of work largely carried out through research activities since 2009.

Sufficient information exists at the national, sectoral and local levels to support the development of policy and begin the process of implementing adaptation actions. We have a clearer understanding of climate change impacts and their consequences across a number of key socio-economic sectors to enable an informed process of decision-making to be undertaken on climate change in Ireland. However, a number of important knowledge gaps remain in areas such as coastal and marine, critical infrastructure, emergency planning and human health, which need to be addressed in the near future to provide a fuller picture of climate change impacts for Ireland. A watching brief is required in other areas.

The evidence base continues to be developed through various national and European research programmes. These initiatives are filling key outstanding knowledge gaps in support of policy and implementation. Through collaborations with international research groups, capacity is developing nationally, which is allowing research of the highest calibre to emerge. However, the support for climate change research must be ongoing and sustainable.

Processes have been put in place to support decision-making, such as the development of local authority guidelines and the roll-out of a national climate information platform (Climate Ireland). In addition, capacity building is ongoing through the availability of adaptation training programmes, seminars and workshops to aid decision-making at a sectoral and local level.

Uncertainties remain in relation to both the rate and the extent of climate change impacts that Ireland will experience. These will eventually determine the extent of damage that will occur and/or the level of adaptation that is required to avoid the worst impacts. Rather than being a barrier to actions, these uncertainties should promote consideration of possible risks and the use of appropriate management tools that are designed to deal with risk. Deferred actions may be more costly in the longer term.

Appropriate steps to assess risks and identify response options are therefore required. We regard this “Tier 1” assessment as an essential first step in scoping priority climate sensitivities and hazards across a number of sectors. This then needs to be supplemented by detailed vulnerability and risk analysis at a sectoral and local level that take account of sensitivities, adaptive capacity and resilience to climate change. Based on these assessments, decision-makers should be equipped to understand their exposure to climate change and take the necessary adaptation actions.

4.2 Recommendations

Adaptation actions will be required to avoid the adverse impacts of climate change and take advantage of any opportunities that may arise. In order to facilitate this process, an adaptation framework is needed. This would aim to advance work within and across sectors at a number of levels, through advancing the knowledge base, building capacity, communication of scientific knowledge and the implementation of actions. This adaptation framework would enable synergies between groups, generate understanding and learning (especially in relation to cross-cutting issues) and avoid duplication of efforts. The framework would encompass:

- advancement of the knowledge base and capacity building;
- development of sectoral risk and vulnerability assessment;
- development and assessment of adaptation options (including costs and benefits);
- development and implementation of effective governance structures.

4.2.1 Advancing the knowledge base

Development of the scientific knowledge base on climate change is ongoing at a national and international level. Most recent advances are those supported by the EU Horizon 2020 research programme and research calls under the Joint Programming Initiative Climate. The activities supported under these instruments range from research in fundamental sciences and climate services to socio-economic analysis of impacts. Key elements of this process for Ireland include:

- development and sustained support of observation systems of essential climate variables and analysis of trends and changes;
- improvement of climate projections and near-time climate forecasting, e.g. periods from years to decades as well as mid- and end of century information;
- support for the development of analysis of systems' fundamental processes that drive the rate and extent of climate change, e.g. oceans systems and precipitation;
- greater understanding of slow-onset climate change and changes in weather extremes (e.g. precipitation and storms).

Future requirements

Improved structures and processes are required to build capacity and advance information exchanges, especially with practitioners and sectoral experts. This would improve targeting of analyses and identification of gaps in knowledge and the co-development of climate services between the research community, practitioners and end users. In synthesising the material for this report, a number of knowledge gaps are now evident, which need to be addressed for a clearer understanding of the full impacts of climate change for Ireland.

The aims would include:

- filling the outstanding knowledge gaps in relation to climate impacts to the marine and coastal environment, agriculture and food security, human health, critical infrastructure and emergency planning;
- analysis of current and emerging vulnerabilities and the identification of key areas for adaptation actions;
- development of vulnerability and process indicators to track progress on implementation of adaptation actions;
- improved understanding of resilience and adaptive capacity;
- sustainability of the shared information platform (Climate Ireland) for the research community, practitioners, policymakers and general public;
- building capacity among the planning and policy-making community, through provision of outreach material, training and guidance tools.

4.2.2 Development of sectoral risk and vulnerability assessment

The development of appropriate climate change risk and vulnerability assessments and techniques is required to underpin adaptation decision-making. In developing a common approach across levels of governance, it should be possible to progress common objectives, avoid maladaptation, recognise and deal with cross-sectoral and cumulative issues and enable monitoring and reporting to national and international processes.

Future requirements

- A national-level climate change risk assessment is required to set out priority climate risks for Ireland and to provide an analysis of the implications of cross-sectoral and cumulative risks.
- Information is needed on external impacts of climate change on vulnerable domestic markets and supply chain management and on the impacts of climate-related human migration.
- Identification of possible opportunities for Ireland is needed (e.g. agriculture, tourism, industry).
- Any new approaches to climate risk management should ideally be placed within an adaptive risk management framework.

4.2.3 Development and assessment of adaptation options (including costs and benefits)

The development and assessment of adaptation options required to manage climate risk must include a range of considerations that include grey, green and soft approaches. The assessment of adaptation options should be based on a multi-criteria analysis that would include consideration of efficacy, costings, win–win situations, etc. Although a body of research is emerging on costing climate change impacts and adaptation, there are still substantial gaps in our knowledge of what climate change is and how much it will cost the Irish state (public and private) over the coming decades.

Future requirements

- A full range of adaptation options must be included in decision-making, with particular attention paid to green approaches (e.g. green infrastructure).
- The costs of current and future climate change impacts and adaptation must be established for a range of key sectors. This must be based on a consistent framework applicable across all sectors and relevant to different types of impact to ensure comparability and consistency in the use of climatic and socio-economic projections.
- The role of the insurance industry must be established, particularly in response to extreme weather events.
- Cross-sectoral comparative metrics and indicators should be developed to enable high-level assessment of the scale and urgency of adaptation requirements.
- Tools should be created for the assessment of the effects on other sectors, up- or downstream in supply chains, macroeconomic (general equilibrium) effects and changes in behaviour as a result of changes in risk exposure (moral hazard risk) of adaptation measures.
- Information must be made available on sources of funding for adaptation actions.

4.2.4 Development and implementation of effective governance structures

In the EU Member States, governance bodies are common ways to co-ordinate adaptation actions across sectors and levels of governance (EEA, 2014). Nationally, the multilevel governance of adaptation is being co-ordinated by the Department of Communications, Climate Action and Environment (DCCAE) through a National Adaptation Steering Committee and other supports. The aim is to progress sectoral and regional adaptation planning, and encourage sharing of knowledge and learning, while avoiding maladaptation, conflicts of interests, and poorly integrated planning and decision-making with expensive, unjust and far-reaching consequences.

Future requirements

- Further and deeper horizontal and vertical co-ordination of adaptation efforts as the implementation of adaptation progresses.
- The participation of multiple stakeholders, including the business and local communities, must be explored with a view to ratcheting up adaptation action at all levels of decision-making.

The authors look forward to engagement with other groups in further improving, elucidating and developing these recommendations.

References

Abdalla, M., Jones, M., Williams, M., 2010. Simulation of N_2O fluxes from Irish arable soils: effect of climate change and management. *Biology and Fertility of Soils* 46(3): 247–260.

Arent, D.J., Tol, R.S.J., Faust, E., Hella, J.P., Kumar, S., Strzepek, K.M., Tóth, F.L. and Yan, D., 2014. Key economic sectors and services. In Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White, L.L. (eds), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, pp. 659–708.

Bahn, M., Lattanzi, F.A., Hasibeder, R., Wild, B., Koranda, M., Danese, V., Brüggemann, N., Schmitt, M., Siegwolf, R. and Richter, A., 2013. Responses of below ground carbon allocation dynamics to extended shading in mountain grassland. *New Phytologist* 198: 116–126.

Berry, H., Bowe, K.J. and Kjellstrom, T., 2010. Climate change and mental health: a causal pathways framework. *International Journal of Public Health* 55(2): 123–132.

Black, K., Xenakis, G. and Ray, D., 2010. Climate change impacts and adaptive strategies. *Irish Forestry* 67: 66–85.

Bjørnæs, C., 2010. *A Guide to Representative Concentration Pathways.* Stockholm Environment Institute. Available online: https://www.sei-international.org/mediamanager/documents/A-guide-to-RCPs.pdf

Boelens, R., Minchin, D. and O'Sullivan, G., 2005. Climate Change: Implications for Ireland's Marine Environment and Resource. Marine Foresight Series No. 2. Marine Institute, Galway. Available online: http://oar.marine.ie/handle/10793/560

Bullock, C., Krtesch, C. and Candon, E., 2008. *The Economic and Social Aspects of Biodiversity. Benefits and Costs of Biodiversity in Ireland.* Department of Environment, Heritage and Local Government, Dublin.

Caffarra, A., Zottele, F., O'Neill, B., Gleeson, E., McGrath, R. and Donnelly, A., 2013a. Predicting changes in bud burst phenology under climate change scenarios for Ireland through use of models. In Donnelly, A. and O'Neill, B. (eds), *Climate Change Impacts on Phenology: Implications for Terrestrial Ecosystems*. CCRP Report No. 22. Environmental Protection Agency, Johnstown Castle, Ireland.

Caffarra, A., Zotelle, F., Gleeson, E. and Donnelly, A., 2013b. Spatial heterogeneity in the timing of birch budburst in response to future climate warming in Ireland. *International Journal of Biometeorology* 58: 509–519.

Cameron, E., 2014. *Climate Change: Implications for Agriculture*. University of Cambridge, Cambridge.

Casal, G., Lavender, S., Cusack, C. and O'Rourke, E., 2017. Spatio-temporal variability of sea surface temperature in Irish waters (1982–2015) using AVHRR sensor. *Journal of Sea Research* (in press).

Chalmers, P., 2014. *Climate Change: Implications for Buildings. Key Findings from the Intergovernmental Panel on Climate Change Fifth Assessment Report*. Cambridge University Press, Cambridge.

Coll, J and Sweeney, J., 2013. *Current and Future Vulnerabilities to Climate Change in Ireland*. CCRP Report No. 29. Environmental Protection Agency. Johnstown Castle, Ireland.

Coll, J., Bourke, D., Gormally, M., Skeffington, M.S. and Sweeney J., 2013. *Winners and Losers: Climate Change Impacts on the Biodiversity in Ireland*. Environmental Protection Agency, Johnstown Castle, Ireland. Available online: http://www.epa.ie/pubs/reports/research/climate/climatechangeresearchreportnumber19.html

Coll, J., Bourke, D., Skeffington S.M. and Gormally, M., 2014. Projected loss of active blanket bogs in Ireland. *Climate Research* 59: 103–115. DOI: 10.3354/cr01202. Available online: http://www.researchgate.net/profile/John_Coll2/publication/257991879_Projected_loss_of_active_blanket_bogs_in_Ireland/links/5474a7380cf245eb436deba5.pdf

Collins, B., Balmforth, D., Rooke, D., Scott, J., Wilkinson, M., Davies, P., Warry, P. and Fox, T., 2011. *Infrastructure, Engineering, and Climate Change Adaptation – Ensuring Services in an Uncertain Future*. Royal Academy of Engineers, London.

Cullen, E., 2008. *7th Scientific Statement: Climate Change and Health in Ireland*. Royal Irish Academy, Dublin.

DAFM (Department of Agriculture, Food and the Marine), 2011. *Annual Review and Outlook for Agriculture, Fisheries and Food*. DAFM, Dublin.

DAFM (Department of Agriculture, Food and the Marine), 2015. *Annual Review and Outlook for Agriculture, Food and the Marine*. DAFM, Dublin.

DECLG (Department of Environment, Community and Local Government), 2012a. *Building Resilience to Climate Change*. National Climate Change Adaptation Network. Department of Environment, Community and Local Government, Dublin.

DECLG (Department of Environment, Community and Local Government), 2012b. *Reform for Water Sector in Ireland*. Position Paper. Department of Environment, Community and Local Government, Dublin.

Department of Arts, Heritage and the Gaeltacht, 2011. *Actions for Biodiversity 2011–2016 – Ireland's National Biodiversity Plan*. Department of Arts, Heritage and Gaeltacht, Ireland.

Department of Transport, Tourism and Sport. Overview of tourism industry. Available online: http://www.dttas.ie/tourism

Desmond, M. and Shine, T., 2012. *National Adaptive Capacity Assessment*. Environmental Protection Agency, Johnstown Castle, Ireland. Available online: http://www.epa.ie/pubs/reports/research/climate/CCRP_17_web.pdf

Devoy, R.J.N., 2008. Coastal vulnerability and the implications of sea-level rise for Ireland. *Journal of Coastal Research* 24(2): 325–341.

Desmond, M., O'Brien, P. and McGovern, F., 2009. *A Summary of the State of Knowledge of Climate Change Impacts for Ireland*. CCRP Report No. 1. Environmental Protection Agency, Johnstown Castle, Ireland.

Dong-Gill, K., Rafique, R., Leahy, P., Cochrane, M. and Kiely, G., 2013. Estimating the impact of changing fertiliser application rate, land use and climate on nitrous oxide emissions in Irish grasslands. *Plant and Soil* 372: 55–71.

Donnelly, A. and O'Neill, B., 2013. *Climate Change Impacts on Phenology: Implications for Terrestrial Ecosystems*. CCRP Report No. 22. Environmental Protection Agency, Johnstown Castle, Ireland.

Dwyer, N., 2012. *The Status of Ireland's Climate, 2012*. EPA Report No. 26. Environmental Protection Agency, Johnstown Castle, Ireland. Available online: http://www.met.ie/UserMediaUpl/file/CCRP_26.pdf

EC (European Commission), 2007. Green Paper from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions "Adapting to climate change in Europe – options for EU action". COM(2007) 354 final, 29.6.2007, Brussels.

EC (European Commission), 2009. White Paper from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions "Adapting to climate change: towards a European Framework for Action". COM(2009) 147/4, Brussels.

EC (European Commission), 2013. *Adapting infrastructure to climate change*. Commission Staff Working Document SWD(2013) 137 final, 16.4.2013, Brussels.

EEA (European Environment Agency), 2010. *EU 2010 Biodiversity Baseline*. EEA Technical Report No. 12/2010. EEA, Copenhagen

EEA (European Environment Agency), 2012. *Climate Change, Impacts and Vulnerability in Europe 2012. An Indicator-based Report*. EEA Report 12/2012. EEA, Copenhagen.

Elliot, C., 2014. *Climate Change Ireland: The Potential Impacts of Climate Change on Food Safety from an Island of Ireland Perspetive*. Safefood: Cork.

EPA (Environmental Protection Agency), 2008. *Ireland's Environment*. EPA, Johnstown Castle, Ireland.

Feser, F., Barcikowska, M., Krueger, O., Schenk, F., Weisse, R. and Xia, L., 2015. Storminess over the North Atlantic and northwestern Europe – a review. *Quarterly Journal of the Royal Meteorological Society* 141: 350–382. DOI: 10.1002/qj.2364.

Finn, J., Ó'hUallacháin, D., Keena, C., Hyde, T., Moran, J. and Regan, R., 2010. Halting biodiversity loss by 2020-implications for agriculture. *TResearch* 5(4): 12–13.

Fitter, A.H. and Fitter, R.S.R., 2002. Rapid changes in flowering time in British plants. *Science* 296: 1689.

Fitzgerald, J.B., Brereton, A.J. and Holden, N.M., 2009. Assessment of the adaptation potential of grass-based dairy systems to climate change in Ireland – the maximised production scenario. *Agricultural and Forest Meteorology* 149: 244–255.

Flood, S., 2013. *Projected Economic Impacts of Climate Change on Irish Agriculture*. Stop Climate Chaos, Dublin. Available online: http://www.stopclimatechaos.ie/download/pdf/projected_economic_impacts_of_climate_change_on_irish_agriculture_oct_2013.pdf

Flood, S. and Sweeney, J., 2012. *Quantifying Impacts of Potential Sea Level Rise Scenarios on Irish Citites.* In Otto-Zimmermann, K. (ed.), *Resilient Cities* II. Springer Netherlands, pp. 37–52.

Forest Services, 2014. *Ireland's Forests – Annual Statistics 2014*. Department of Agriculture, Food and the Marine, Dublin.

Forestry Focus, n.d. Frost damage. Available online: http://www.forestryfocus.ie/growing-forests-3/threats-to-forests/frost-damage/

Forfás, 2010. *Adaptation to Climate Change: Issues for Business*. Summary Report August 2010. Forfás, Dublin.

Gagen, M., Zorita, E., McCarroll, D., Zahn, M., Young, G. and Robertson, I., 2016. North Atlantic summer storm tracks over Europe dominated by internal variability over the past millennium. *Nature Geoscience* 9(8): 630–635.

Gallagher, S. et al. Wave climate projections for Ireland for the end of the 21st century including analysis of EC-Earth winds over the North Atlantic Ocean. *International Journal of Climatology* 36:4592–4607.

Gleeson, E., McGrath, R. and Treanor, M., 2013. *Ireland's Climate: The Road Ahead*. Met Éireann, Dublin. Available online: http://www.met.ie/publications/IrelandsWeather-13092013.pdf

Hansen, J., Sato, M., Hearty, P., Ruedy, R., Kelley, M., Masson-Delmotte, V., Russell, G., Tselioudis, G., Cao, J., Rignot, E., Velicogna, I., Kandiano, E., von Schuckmann, K., Kharecha P., Legrande, A.N., Bauer, M., and Lo, K.-W., 2015. Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climatemodeling, and modern observations that 2ºC global warming is highly dangerous. *Atmospheric Chemistry and Physics Discussion* 15: 20059–20179.

Hall, J., Murphy, C. and Sweeney, J., 2012. *Robust Adaptation to Climate Change in the Water Sector in Ireland*. Environmental Protection Agency, Johnstown Castle, Ireland.

Hennessy, T., 2010. *The Impact of Climate Change on Irish Farming*. Project No. 5623. Teagasc, Carlow, Ireland.

IAE (Irish Academy of Engineering), 2009. *Ireland at Risk – Critical Infrastructure, Adaptation for Climate Change*. IAE, Dublin.

IPCC (Intergovernmental Panel on Climate Change), 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds). Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel on Climate Change), 2012. Summary for policymakers. In Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M. and Midgley, P.M. (eds), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge University Press, Cambridge, pp. 3–24.

IPCC (Intergovernmental Panel on Climate Change), 2013a. Summary for policymakers. In Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (eds), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel on Climate Change), 2013b. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex. V., & Midgley, P.M. (eds). Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel on Climate Change), 2014a. Summary for policymakers. In Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White, L.L. (eds), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, pp. 1–32.

IPCC (Intergovernmental Panel on Climate Change), 2014b. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White, L.L. (eds). Cambridge University Press, Cambridge, pp. 688

Irish Water, 2015. *Draft Water Services Strategic Plan*. Irish Water, Dublin.

Kelly, B. and Stack, M., 2009. *Climate Change, Heritage and Tourism: Implications for Ireland's Coast and Inland Waterways*. Heritage Council and Fáilte Ireland, Dublin. Available online: http://www.heritagecouncil.ie/content/files/climate_change_heritage_tourism_summary_2009_1mb.pdf

Khalil, M.I., Kiely, G., O'Brien, P. and Muller, C., 2013. Organic carbon stocks in agricultural soils in Ireland using combined empirical and GIS approaches. *Geoderma* 193: 222–235

Larsen, K.M.H., Gonzalez-Pola, C., Fratantoni, P., Beszczynska-Möller, A., and Hughes, S.L. (eds), 2016. *ICES Report on Ocean Climate 2015*. ICES Cooperative Research Report No. 331. International Council for the Exploration of the Sea (ICES), Copenhagen.

Lenton, T.M, Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S. and Schellnhuber, H.J., 2007. Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences of the United States of America* 105:1786–93. Available online: http://www.pnas.org/content/105/6/1786.full.pdf

Leahy, P., Kiely, G. and Scanlon, T.M., 2004. Managed grasslands: a greenhouse gas sink or source? *Geophysical Research Letters* 31: L20507.

Lowe, J.A., Howard, T., Pardaens, A., Tinker, J., Jenkins, G., Ridley, J., Leake, J., Holt, J., Wakelin, S., Wolf, J., Horsburgh, K., Reeder, T., Milne, G., Bradley, S., and Dye, S., 2009. *UK Climate Projections Science Report: Marine and Coastal Projections*. Available online: http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87905&

Lyons, S., Morgenroth, E. and Tol, R.S.J., 2013. Estimating the value of lost telecoms connectivity. *Electronic Commerce Research and Applications* 12: 40–51.

McElwain, L. and Sweeney, J., 2007. *Key Meteorological Indicators of Climate Change in Ireland*. Environmental Research Centre Report. Environmental Protection Agency, Johnstown Castle, Ireland.

McDermot. T., 2016. *Scoping the Costs of Climate Impacts and Adaptation for Ireland*. Environmental Protection Agency, Johnstown Castle, Ireland.

McGrath, T., Kivimae, C., Tanhua, T., Cave, R.R. and McGovern, E., 2012. Inorganic carbon and pH levels in the Rockall Trough 1991–2010. *Deep Sea Research Part I: Oceanographic Research Papers* 68: 79–91.

Maguire, C., Gallagher, K., Maggs, C., Dick, J, Caffrey, J., O'Flynn, C., Fitzpatrick, U., Kelly, J. and Harrod, C., 2011. *Alien Invasive Species in Irish Water Bodies*. STRIVE Report No. 83. Environmental Protection Agency, Johnstown Castle, Ireland. Available online: http://www.epa.ie/pubs/reports/research/water/strivereport83.html

Malone, S. and O'Connell, C., 2009. *Ireland's Peatland Conservation Action Plan 2020 – Halting the Loss of Peatland Biodiversity.* Irish Peatland Conservation Council, Kildare.

Matthews, T., Mullan, D., Wilby, R.L., Broderick, C. and Murphy, C., 2016. Past and future climate change in the context of memorable seasonal extremes. *Climate Risk Management* 11: 37–52.

Mitchell, D., Heaviside, C., Vardoulakis, S., Huntingford, C., Masato,G., Guillod, B.P., Frumhoff, P., Bowery, A., Wallom, D. and Allen, M., 2016. Attributing human mortality during extreme heat waves to anthropogenic climate change. *Environmental Research Letters* 11: 074006.

Myers, S., Zanobetti, A., Kloog, I., Huybers, P., Leaky, A.D.B., Bloom, A.J., Carlisle, E., Dietterich, L.H., Fitzgerald, G., Hasegawa, T., Holbrook, N.M., Nelson, R.L., Ottman, M.J., Raboy, V., Sakai, H., Sartor, K.A., Schwartz, J., Seneweera, S., Tausz, M. and Usui, Y., 2014. Increased CO_2 threatens human nutrition. *Nature* 510(7503): 139–142. DOI: 10.1038/nature13179.

Murphy, C. and Charlton, R., 2007. Climate change and water resources. In Sweeney, J., Albanito, F., Brereton, A., Caffarra, A., Charlton, R., Donnelly, A., Fealy, R., Fitzgerald, J., Holden, N., Jones, M. and Murphy, C. (eds), *Climate Change: Refining the Impacts for Ireland*. Environmental Protection Agency, Johnstown Castle, Ireland, pp. 39–81.

National Directorate for Fire and Emergency Management, Department of Environment, Community and Local Government, 2014. *Report on Severe Weather from 13th December 2013 to 6th January 2014*. Department of Environment, Community and Local Environment, Dublin. Available online: http://www.environ.ie/en/Publications/Community/FireandEmergencyServices/FileDownLoad,36547,en.pdf

Nolan, P., 2015. *Ensemble of Regional Climate Model Projections for Ireland*. Environmental Protection Agency, Johnstown Castle, Ireland.

Nolan, G., Gillooly, M. and Whelan, K. (eds), 2010. *Irish Ocean Climate and Ecosystem Status Report 2009*. Marine Institute, County Galway, Available online: http://oar.marine.ie/handle/10793/81?mode=full

Nolan P., Goodman, P., O'Sullivan, J., Sweeney, C., Gleeson, E. and McGrath, R., 2013. Climate change: impacts on Irish temperatures. In Gleeson, E., McGrath, R. and Treanor, M. (eds), *Ireland's Climate: The Road Ahead*. Met Éireann, Dublin, pp. 17–19. Available online: http://www.met.ie/publications/IrelandsWeather-13092013.pdf

O'Dowd, C., Cave, R., McGovern, E., Ward, B., Kivimae, C., McGrath, T., Stengel, D. and Westbrook, G., 2011. *Impacts of Increased Atmospheric CO_2 on Ocean Chemistry and Ecosystems*. Marine Institute, Galway. Available online: http://oar.marine.ie/bitstream/10793/703/1/Impacts%20of%20Increased%20Atmospheric%20CO2%20on%20Ocean%20Chemistry%20and%20Ecosystems.pdf

O'Driscoll, E., 2014. *An Overview of the Irish Forestry and Forest Products Sector 2014*. Irish Forestry and Forest Products Association, Dublin.

O'Dwyer, B., 2017. Climate Ireland. Available online: http://www.climateireland.ie/

Olbert, I.A., Dabrowski, T., Nash, N. and Hartnett, M., 2012. Regional modelling of the 21st century climate changes in the Irish Sea. *Continental Shelf Research* 41: 48–60.

O'Neill, B., Bond, K., Tyner, A., Sheppard, R., Bryant, T., Chapman, J., Bell, J. and Donnelly, A., 2012. Climatic warming advancing phenology of moth species in Ireland. *Entomologia Experimentalis et Applicata* 143: 74–88.

O'Regan, E., 2013. Mercury rising: what climate change will mean for butterflies in Ireland. In Gleeson, E., McGrath, R. and Treanor, M. (eds), *Ireland's Climate: the Road Ahead*. Met Éireann, Dublin, pp. 41–46.

O'Sullivan, J., Sweeney, C., Nolan, P., Gleeson, E., 2015. A high-resolution, multi-model analysis of Irish temperatures for the mid-21st century. *International Journal of Climatology* 36: 1256–1267.

Pascal, M., 2011. *An Analysis of the Mortality Risks Associated with Heat and Heat Waves in Ireland, to Assist in Planning for Climate Change*. PhD Thesis. Dublin Institute of Technology, Dublin. Available online: http://arrow.dit.ie/cgi/viewcontent.cgi?article=1126&context=sciendoc

Pascal, M., Goodman, P., Clancy, L. and Schwartz, J., 2013. *Extreme Temperatures and Mortality in Ireland*. Environmental Protection Agency, Johnstown Castle, Ireland.

Rahmstorf, S., Box, J.E., Feulner, G., Mann, M.E., Robinson, A., Rutherford, S. and Schaffernicht, E.J., 2015. Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. *Nature Climate Change* 5: 475–480. DOI: 10.1038/NCLIMATE2554.

Ray, D., Xenakis, G., Tene, A. and Black, K., 2009. Developing a site classification system to assess the impact of climate change on species selection in Ireland. *Journal of Irish Forestry* 66: 101–121.

Reichstein, M., Bahn, M., Ciais, P., Frank, D., Mahecha, M.D., Seneviratne, S.I., Zscheischler, J., Beer, C., Buchmann, N., Frank, D.C., Papale, D., Rammig, A., Smith, P., Thonicke, K., van der Velde, M., Vicca, S., Walz, A. and Wattenbach, M., 2013. Climate extremes and the carbon cycle. *Nature* 500: 287–295.

Renou-Wilson, F., Bolger, T., Bullock, C., Convery, F., Curry, J., Ward, S., Wilson, D. and Müller, C., 2011. *BOGLANDS: Sustainable Management of Peatlands in Ireland.* STRIVE Report 75. Environmental Protection Agency, Ireland. Available online: http://www.epa.ie/pubs/reports/research/land/strive75.html

Revi, A., Satterthwaite, D.E., Aragón-Durand, F., Corfee-Morlot, J., Kiunsi, R.B.R., Pelling, M., Roberts, D.C. and Solecki, W., 2014. Urban areas. In Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White, L.L. (eds), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, pp. 535–612.

Rydin, H. and Jeglum, J., 2006. *The Biology of Peatlands.* Biology of Habitats. Oxford University Press, New York, NY.

Salmon, N., 2013. Tourism and climate change in Ireland. In Sweeney, J., Bourke, D., Coll, J., Flood, S., Gormally, M., Hall, J., McGloughlin, J., Murphy, C., Salmon, N., Sheehy Skeffington, M. and Smyth, D., *Co-ordination, Communication and Adaptation for Climate Change in Ireland: An Integrated Approach (COCOADAPT)*. CCRP Report No. 30. Environmental Protection Agency, Johnstown Castle, Ireland.

Saunders, M., Tobin, B., Sweeney, C., Gioria, M., Benanti, G., Cacciotti, E., Osborne, B.A., 2014. Impacts of exceptional and extreme inter-annual climatic events on the net ecosystem carbon dioxide exchange of a Sitka spruce forest. *Agricultural and Forest Meteorology* 184: 147–157.

Schellnhuber, H.J., Rahmstorf, S. and Winkelmann, R., 2016. Why the right climate target was agreed in Paris. *Nature Climate Change* 6: 649–653. Available online: www.nature.com/natureclimatechange

Schulte, R.P.O. and Lanigan, G. (eds), 2011. *Irish Agriculture, Greenhouse Gas Emissions and Climate Change: Opportunities, Obstacles and Proposed Solutions*. Teagasc, Carlow.

Schulte, R.P.O., Richards, K., Daly, K., Kurz, I., McDonald, E.J. and Holden, N.M., 2006. Agriculture, meteorology and water quality in Ireland: a regional evaluation of pressures and pathways of nutrient loss to water. *Biology and Environment: Proceedings of the Royal Irish Academy* 106B(2): 117–133.

Schulte, R.P.O., Creamer, R.E., Donnellan, T., Farrelly, N., Fealy, R., O'Donoghue, C. and O'hUallachain, D., 2014. Functional land management: a framework for managing soil-based ecosystem services for the sustainable intensification of agriculture. *Environmental Science & Policy* 38: 45–58. Available online: http://www.sciencedirect.com/science/article/pii/S1462901113002104

Shrestha, S., Abdalla, M., Hennessy, T., Forristal, D., and Jones, M.B., 2015. Irish farms under climate change – is there a regional variation on farm responses? *The Journal of Agricultural Science* 153: 385–398. Available online: https://www.cambridge.org/core/journals/journal-of-agricultural-science/article/irish-farms-under-climate-change-is-there-a-regional-variation-on-farm-responses/166D3D2D3989B05DB311F785A3414AF3. DOI: 10.1017/S0021859614000331.

Statistical Yearbook of Ireland, 2014a. Agriculture accounts. Central Statistics Office. Available online: http://www.cso.ie/en/releasesandpublications/ep/p-syi/statisticalyearbookofireland2014/agriculture/agricultureaccounts/

Statistical Yearbook of Ireland, 2014b. National accounts. Central Statistics office. Available online: http://www.cso.ie/en/releasesandpublications/ep/p-syi/statisticalyearbookofireland2014/economy/nationalaccounts/

Stainforth, D., Allen, M., Tredger, E. and Smith, L., 2007. Confidence, uncertainty and decision-support relevance in climate predictions. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 365(1857): 2145–2161.

Steele-Dunne, S., Lynch, P., McGrath, R., Semmler, T., Wang, S., Hanafin, J. and Nolan P., 2014. The impacts of climate change on hydrology in Ireland. *Journal of Hydrology* 356: 28–45.

Surminski, S., Aerts, J.C.J.H., Botzen, W.J.W., Hudson, P., Mysiak, J. and Pérez-Blanco, C.D., 2015. Reflections on the current debate on how to link flood insurance and disaster risk reduction in the European Union. *Natural Hazards* 79: 1451–1479. DOI: 10.1007/s11069–015–1832–5.

Sweeney, J., Donnelly, A., McElwain, L. and Jones, M., 2002. *Climate Change: Indicators for Ireland*. Environmental Protection Agency, Johnstown Castle, Ireland.

Sweeney, J., Bourke, D., Coll, J., Flood, S., Gormally, M., Hall, J., McGloughlin, J., Murphy, C., Salmon, N., Sheehy Skeffington, M. and Smyth, D., 2013. *Co-ordination, Communication and Adaptation for Climate Change in Ireland: an Integrated Approach (COCOADAPT)*. CCRP Report No. 30. Environmental Protection Agency, Johnstown Castle, Ireland.

Stirnemann, R., O'Halloran, J., Geyer, H.-A. and Donnelly, A., 2013. Location of migratory bird records and analysis of trends in relation to temperature variables. In Donnelly, A. and O'Neill, B. (eds), *Climate Change Impacts on Phenology: Implications for Terrestrial Ecosystems*. CCRP Report No.22. Environmental Protection Agency, Johnstown Castle, Ireland, pp. 19–25.

Tanner, T. and Rentschler, J., 2015. Unlocking the triple dividend of resilience – why investing in disaster risk management pays off. The World Bank, Washington, DC, and Overseas Development Institute (ODI), London. Presented at the UN World Conference on Disaster Risk Reduction, March 2015, Sendai, Japan. Available online: http://www.odi.org/tripledividend

Teagasc, 2017. Agriculture in Ireland. Available online: https://www.teagasc.ie/rural-economy/rural-economy/agri-food-business/agriculture-in-ireland/

Tedd, K., Misstear, B., Coxon, C., Daly, D., Williams, T.H., Craig, M., Mannix, A., 2011. *A Review of Groundwater Levels in the South-east of Ireland*. EPA ERC Report No. 17. Environmental Protection Agency, Johnstown Castle, Ireland.

UK CCRA, 2016. *The United Kingdom Climate Change Risk Assessment*. Synthesis Report: Priorities for the Next Five Years. The Committe on Climate Change.

United National Development Programme, 2005. *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*. Cambridge, Cambridge University Press.

van Oldenborgh, G.J., Otto, F.E.L., Haustein, K. and Cullen, H. Climate change increases the probability of heavy rains like those of storm Desmond in the UK – an event attribution study in near-real time. *Hydrology and Earth System Sciences* 12: 13197–13216. DOI: 10.5194/hessd-12-13197-2015.

Vihma, T., 2014. Effects of Arctic sea ice decline on weather and climate: a review. *Surveys in Geophysics* 35: 1175–1214. DOI: 10.1007/s10712-014-9284-0.

Walsh, S. and Dwyer, N., 2012. Rainfall. In Dwyer, N. (ed.), *The Status of Ireland's Climate*. CCRP Report 26. Environmental Protection Agency, Johnstown Castle, Ireland.

Walker, W.E., Hasnoot, M. and Kwakkel, J., 2013. Adapt or perish: a review of planning approaches for adaptation under deep uncertainty. *Sustainability* 5(3): 955–979.

Wang, S., McGrath, R., Hanafin, J., Lynch, P., Semmler, T. and Nolan, P., 2008. The impact of climate change on storm surge over Irish waters. *Ocean Modelling* 25: 83–94.

Watkiss, P. and Hunt, A., 2012. *Cost-effectiveness analysis: decision support methods for adaptation*. MEDIATION Project – Briefing Note 2. Funded by the EC's 7FWP. European Comission, Brussels.

Wheelan, D., 2014. *Irish Forests and Climate Change*. COFORD, Dublin. Available online: http://www.coford.ie/media/coford/content/publications/forestry2030/00504%20Forestry%202030%20Inserts%20-%2004%20Climate%20Change.pdf

Williams, N.H. and Lee, M., 2007. *Ireland at Risk – Possible Implications for Groundwater Resources of Climate Change*. Groundwater Section, Geological Survey of Ireland. IAE Publications, Dublin.

Willows, R.I. and Connell, R.K. (eds), 2003. *Climate Adaptation: Risk, Uncertainty and Decision-making*. UKCIP Technical Report. UK Climate Impacts Programme, Oxford.

Wilson, D., Müller, C. and Renou-Wilson, F., 2013. Carbon emissions and removals from Irish peatlands: current trends and future mitigation measures. *Irish Geography* 46: 1–23.

Abbreviations

EPA	Environmental Protection Agency
GCM	Global climate model
GHG	Greenhouse gas
ICT	Information and communication technology
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	IPCC Fifth Assessment Report which is subdivided into 3 working group reports (WG1: Physical Scientific Basis, WG2: Impacts, Adaptation and Vulnerability and WG3: Mitigation of Climate Change)
MOC	Meridional overturning circulation
NUIG	National University of Ireland, Galway
NUIM	National University of Ireland, Maynooth
OPW	Office of Public Works
RCM	Regional climate model
RCP	Representative concentration pathway
SLR	Sea level rise
SRES	Special Report on Emissions Scenarios
TCD	Trinity College Dublin
THC	Thermohaline circulation
UCC	University College Cork
UCD	University College Dublin

Appendix 1 Experts Consulted in the Development of This Document

Attendees at Review Meeting, Dublin, 4 September 2015

- Dr Barry O'Dwyer, University College Cork (UCC)
- Dr Conor Sweeney, University College Dublin (UCD)
- Dr Craig Bullock, UCD
- Dr Eugene Farrell, National University of Ireland, Galway (NUIG)
- Dr Florence Renou-Wilson, UCD
- Dr John Coll, National University of Ireland, Maynooth (NUIM)
- Dr Matthew Jebb, Botanic Gardens
- Dr Michael Bruen, UCD
- Dr Michael Jones, Trinity College Dublin (TCD)
- Dr Paul Nolan, UCD
- Professor Peter Thorne, NUIM
- Dr Ray McGrath, Met Éireann (retired)
- Professor Robert Devoy, UCC
- Dr Rowan Fealy, NUIM
- Dr Seamus Walsh, Met Éireann
- Dr Thomas McDermott, UCC

Additional Chapter Support

- Dr Conor Murphy, NUIM
- Dr Eleanor O'Rourke, Marine Institute
- Dr Caroline Cusack, Marine Institute
- Dr Nichola Hughes, EPA
- Dr Gary Lanigan, Teagasc

Editorial Support

- Dr Margaret Desmond, EPA/UCC
- Mr Phillip O'Brien, EPA/NUIG
- Dr Frank McGovern, EPA
- Mr Seosamh O'Laoi, Department of Communications, Climate Action and Environment (DCCAE)
- Ms Maria Jacob, EPA (intern)

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

EPA Research Report 223

A Summary of the State of Knowledge on Climate Change Impacts for Ireland

epaResearch
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Authors: Margaret Desmond, Phillip O'Brien and Frank McGovern

Background

The background to this report lies with its predecessor, the first State of Knowledge on Climate Change Impacts for Ireland (Desmond et al, 2009). That report filled a large knowledge gap by providing an authorative synthesis of the available information on climate change impacts and adaptation. Since then we've had the publication of the IPCC 5th Assessment Reports (2013) and numerous national level reports on all aspects of climate change science, impacts and adaptation. In addition, we've begun to see the implementation of adaptation at sectoral and local levels. This new reality has created an urgent need for an updated synthesis report that accurately reflects the scientific advances made nationally in knowledge and information generation. The report represents the distillation of a large body of work, largely carried out through research activities since 2009.

Identifying Pressures

Changes in Ireland's climate are in-line with and similar to relevant global trends. Climate change will have diverse and wide ranging impacts on our environment, society, economic sectors and natural resources. The challenge is to provide decision makers at all levels and the general public with high quality information to make informed decisions on policy development and investments that will be resilient to the impacts of climate change.

This report provides: 1) a summary of observed and projected changes in the Irish climate across a number of key parameters; 2) a synthesis of knowledge of ongoing and anticipated climate change impacts across a number of environmental and economic sectors and: 3) recommendations for further steps required to support policy development and aid the implementation of adaptation nationally.

Informing Policy

The information summarised in this report will assist in the development of coherent and rational decision making at the national, sectoral and local level, namely by:

- Providing a high level synthesis of existing climate change information across a number of key parameters such as temperature, precipitation, sea level rise and extreme weather events;
- Providing a synthesizes of ongoing and anticipated climate change impacts across a large number of environmental and economic sectors;
- Providing a summary of possible adaptation options;
- Identifying knowledge gaps and suggestions on how they might be filled.

Developing solutions

This report provides Irish decision makers with an authorative and timely summary of the state of knowledge on climate change impacts. It will assist the development of adaptation strategies and plans at national, sectoral and local level decision making. It is part of the solution to the societal challenge of transitioning to a climate resilient Ireland.

EPA Research: McCumiskey House,
Richiew, Clonskeagh, Dublin 14.

Phone: 01 268 0100
Twitter: @EPAResearchNews
Email: research@epa.ie

www.epa.ie

EPA Research Webpages
www.epa.ie/researchandeducation/research/