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National Risk Assessment of Impacts of Climate Change: Bridging the Gap to Adaptation Action

Authors: Stephen Flood, Shona Paterson, Ellen O'Connor, Barry O'Dwyer, Hester Whyte, Martin Le Tissier and Jeremy Gault

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Rialtas na hÉireann
Government of Ireland

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.

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

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- the contained use and controlled release of Genetically Modified Organisms *(GMOs)*;
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- 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

National Risk Assessment of Impacts of Climate Change: Bridging the Gap to Adaptation Action

(2016-CCRP-MS.39)

EPA Research Report

Prepared for the Environmental Protection Agency

by

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This report is based on research carried out/data from January 2017 to August 2019. More recent data may have become available since the research was completed.

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.

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Executive Summary

The global climate is changing and having wide-ranging effects on all aspects of society, the environment and the economy. Projections indicate that these changes will continue and intensify into the future. It is indisputable that society needs to take climate change action and, in response, two complementary policies have been adopted: mitigation and adaptation. Mitigation aims to address the causes of climate change by reducing emissions of greenhouse gases and enhancing carbon sinks. Adaptation aims to address the adverse impacts of climate change while taking advantage of any opportunities presented by these changes. However, even if rapid and ambitious global greenhouse gas reductions are implemented, significant changes in climate at global, regional and national scales, and resulting impacts, both positive and negative, are inevitable.

To support planning for adaptation to climate change impacts and their consequences, Climate Change Risk Assessments (CCRAs) aim to further our understanding of the risks posed from the changing climate and, at the same time, provide insights into the nature of the solutions needed to form an integrated part of any climate change adaptation planning process. CCRAs provide a basis for making decisions on whether risks, and what level of those risks, are acceptable to society or the community by obtaining, collating and analysing information on the projected impacts and consequences of climate change. CCRAs then determine how risks deemed unacceptable can be reduced to below threshold levels of acceptability and how potential opportunities can be realised. CCRAs can be carried out at a range of scales, from community level to national, regional and international levels.

Situated in the north-west of Europe, Ireland faces a wide range of risks associated with climate hazards, which derive from slow-onset (rising sea levels), sudden/extreme (storms) and compound (combinations of slow- and sudden-onset) events. This project adopted a tiered assessment approach to assess and capture the range of climate-driven risks faced by Irish society and in accordance with existing national climate policy (e.g. the National Adaptation Framework – NAF) and guidance (e.g. local and sectoral adaptation planning guidelines). This tiered approach provides a methodology to carry out an effective climate risk screening process in the face of a range of constraints linked with finances, personnel, time and data availability. The tiered assessment approach consists of three levels that progress from assessments carried out with limited resources and data availability (first pass) to more advanced assessments requiring significant financial, human and data resources (second and third passes).

This national CCRA draws on existing qualitative and quantitative information to determine and prioritise the range of risks posed by climate change. In order to facilitate policy cohesion and alignment with Ireland's NAF, in this report the findings are presented according to the NAF's four themes: natural and cultural capital, critical infrastructure, water resources and flood risk management, and public health. Moreover, the approach links climate change risks with achievement of planning and development objectives and priorities. By applying a climate lens one can increase understanding of how projected changes in climate, and their associated impacts and consequences, can either challenge or facilitate the achievement of strategic government priorities.

In consultation with key stakeholder groups, priority climate hazards resulting in risks were identified over the short term (0–5 years), medium term (6–20 years) and long term (>50 years). The results indicate that sea level rise, coastal storms and flooding represent the most immediate risks on a national basis, with heat-related risks identified as an increasing risk on a longer term basis. As part of the second-pass activities, these priority hazards were assessed based on the available science and existing national policy to identify key climate-related risks arising from ongoing and projected changes in climate. As part of the third-pass assessment activities, and drawing on detailed information and data, case study examples are provided specifically for these risks associated with sea level rise and urban overheating.

The methodology employed provides a national-scale overview of priority climate change risks in accordance with existing and strategic policy directions. The tiered nature of the assessment provides an iterative approach that supports adaptive management approaches and can be considered as learning by doing, allowing decision-making communities to increase their understanding of the range of risks (first-pass assessment), prioritise these risks through further analyses of their impacts on strategic goals and directions (second-pass assessment) and develop a detailed understanding of priority risks through a third-pass assessment. Importantly, this tiered approach helps identify research gaps to support future and more complex assessments of climate risk. These include the interlinked and cascading nature of climate risks across society.

On this basis, the following recommendations are made:

- Adaptation planning is an iterative process that involves learning by doing; a tiered approach supports the iterative nature of adaptation planning. For example, Ireland’s first round of local and sectoral adaptation plans and strategies is based on a first- to second-pass assessment approach. Current adaptation plans should be evaluated against the CCRA process. To address the barriers to implementation of site-specific adaptation actions, there is a requirement to progress to third-pass assessment methodologies.
- CCRAs and third-pass assessments are based on detailed information and data. There is a requirement to continue to advance the knowledge base, especially in relation to spatially and temporally specific impact studies (observed and projected), vulnerability analysis and adaptation option appraisal.
- Future development and policy decisions will have implications for levels of exposure to climate hazards and associated risks. There is a requirement to include approaches, adapted for Irish conditions, that consider changes in populations and demographics, such as those developed using shared socio-economic pathways, to account for human factors in risk assessment.
- Enhance the engagement of all stakeholders, including the wider community at the local level, and promote the co-production of knowledge and solutions to maximise acceptance of mitigation and adaptation measures.
- There is a clear need to fully inculcate CCRA into the Climate Ireland platform and into climate action mainstreaming in general. CCRA can both inform the identification of adaptation options and, through application of evaluation approaches, e.g. cost–benefit analysis, facilitate the process of deciding on the most favourable adaptation options.

1 Introduction

1.1 Overview

Climate risk results from the interaction of hazards, exposure and vulnerability. While hazards are related to the physical aspects of risks (natural variability and anthropogenic climate change), exposure and vulnerability encompass socio-economic processes (Figure 1.1). Climate Change Risk Assessments (CCRAs) provide a basis for making decisions on whether risks, and what level of those risks, are acceptable to society or the community, and for obtaining, collating and analysing information on how risks deemed unacceptable can be reduced to below threshold levels of acceptability and how potential opportunities can be realised. Note that this project has emphasised the need to consider both risks (i.e. negative impacts) and opportunities (i.e. positive impacts).

One essential outcome of a risk assessment is an informed process that leads to increased understanding and management of climate risks for societal well-being, infrastructure and other assets essential for people (personal health) and the environment, looking above and beyond economic security concerns. The extent of risk from climate change derives from the sum of the magnitude of the *hazard* (e.g. flooding, heatwave), the relative “value”/importance/quantity of what is *exposed* to the hazard (people, infrastructure, environment) and the *vulnerability* of what is exposed (the sensitivity of the exposed assets/communities to the hazard and the ability or lack thereof to cope and adapt to the hazard) (see Figure 1.1).

Risks can include both slow-onset and sudden-onset events and can impact across a range of societal and economic systems and time and spatial scales. To clarify, climate risks arise not only from extreme weather events, but also from gradual changes in “baseline” conditions, such as sea level rise (SLR) increasing the risk of coastal flooding and temperature rise influencing the types of crops that can be grown. Furthermore, many risks are compounded by interactions between and/or cascade effects of other risks. For example, SLR can exacerbate extreme weather events such as storm surges and floods.

Socio-economic questions and measurements are important in quantifying the impacts and implications

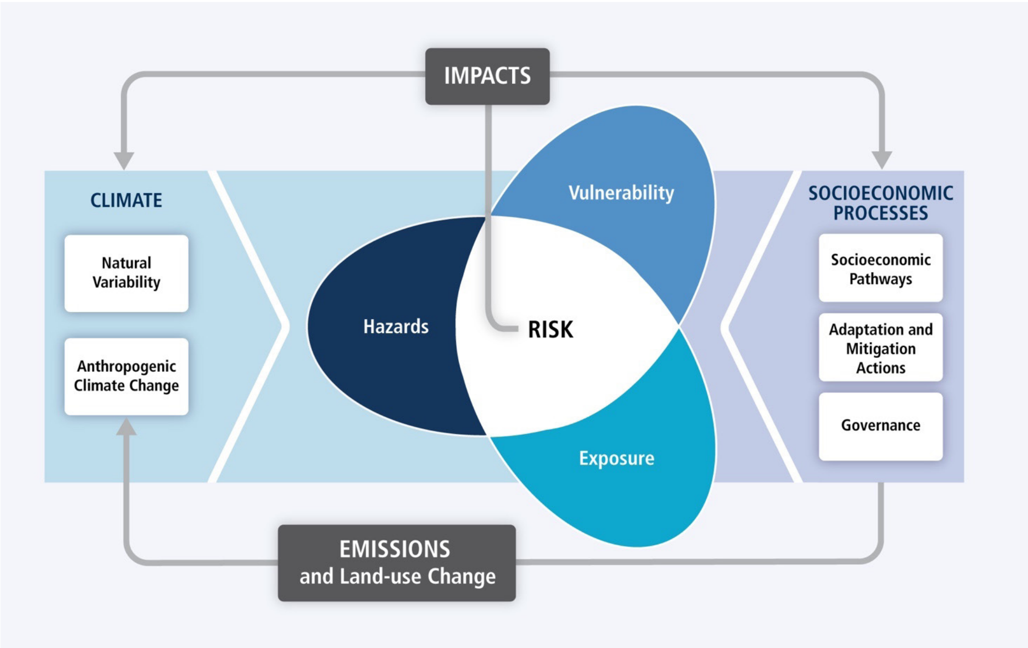

Figure 1.1. Schematic overview showing the integrative concept of climate risk, as presented by the Intergovernmental Panel on Climate Change (2014).

of the inter-related climate change risks, mitigation and adaptation (Hsiang and Kopp, 2018). There is an increasing acknowledgment of the financial risk implications of climate change impacts. The latest Global Risks Report (WEF, 2019) highlighted extreme weather events as the greatest global risk for 2019. Failure of climate change mitigation and adaptation is ranked as the second greatest global risk. Biodiversity loss and ecosystem collapse, water crises and man-made environmental disasters are all ranked in the top 10 risks (WEF, 2019). However, despite the intensification of global risks, a collective will to tackle them appears to be lacking (WEF, 2019). Mitigating climate risk is also high on the agenda of the World Bank Group (2019). It recommends a scaling up of action on adaptation and resilience building and, with other organisations, makes a strong link between climate adaptation and achievement of key development objectives, including the Sustainable Development Goals (SDGs), Sendai Framework for Disaster Risk Reduction 2015–2030 and Paris Agreement (Murray *et al*., 2017; UNFCCC, 2017; World Bank Group, 2017, 2019). It is clear that the challenge of managing climate change risks is substantial and will require significant action and investment across communities at all scales.

Risks faced by communities globally show an increasing trend that is expected to continue as climate change alters existing patterns of social and economic activity (e.g. agricultural practices, land use). Climate change drives increases in the frequency and severity of extreme weather events and resultant loss and damages, and changes to “baseline” conditions (such as SLR increasing the risk of coastal flooding and temperature rise affecting the types of crops that can be grown), and alters patterns of social and economic activity that have arisen. The 2015 adoption of landmark United Nations (UN) agreements – the Sendai Framework, the SDGs and the outcomes from the COP 21 Paris Climate Conference (Figure 1.2) – represents a global awakening to the interconnected nature of the risks of global climate change faced by communities at international, national and local scales (Murray *et al*., 2017). CCRAs can support the implementation of enhanced adaptation action and the development of integrated approaches to adaptation, sustainable development and disaster risk reduction owing in part to their shared themes, scopes and objectives. Adaptation to climate risk is critical to support resilience-building measures and move away from managing crises to proactively reducing their risks.

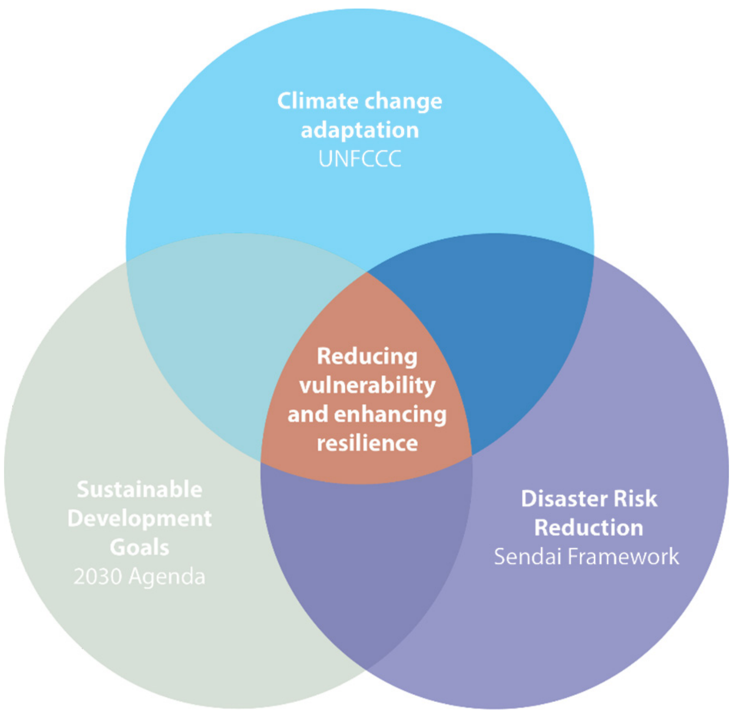

Figure 1.2. Opportunities and options for integrating climate change adaptation with the SDGs and the Sendai Framework for Disaster Risk Reduction 2015–2030. Source: UNFCCC (2017).

1.2 Aims and Approach

The aim of an effective risk assessment framework is to provide a sound basis for making decisions on whether or not risks are acceptable and obtaining reliable information on how those risks can be reduced and opportunities realised. Diverse agencies have developed different approaches to risk assessment with the view of increasing capacity to make confident and balanced decisions about risks on a consistent and reliable basis (International Organization for Standardization ISO 31000) and adaptation action (ISO/DIS 14091). The existence of different approaches, orientations and assessment questions demonstrates the complex nature of dealing with the risks associated with the social and biophysical impacts of climate change and leads to multiple viewpoints on the "best" approach. Different levels of the assessment process, each with supporting goals and different levels of data and resource availability, have also been identified (Tonmoy *et al*., 2019).

This report has been informed by the large body of peer-reviewed scientific literature and grey literature on the subjects of climate change, associated impacts, degree to which humans and natural systems are vulnerable to these impacts under different socio-economic futures and level of adaptation that is occurring or is planned. Numerous data sources were examined for information on climate, both current and projected, threats, vulnerabilities, exposures, sensitivities and risks, as well as adaptation, mitigation and adaptive capacity measures. Sources included individual sector plans and reports, research council-led project outputs and technical reports, academic papers and international research, as well as major syntheses [e.g. the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report].

In accordance with the key sectors identified in the National Adaptation Framework (NAF), evidence has specifically been gathered across nine sectors in Ireland, as well as from available cross-sectional assessments (Figure 1.3). This report aims to provide information to policymakers on the exposure of Ireland to key hazards and the vulnerability of Ireland to these hazards and, on this basis, identify future risks and opportunities arising from climate change. The results of the assessment are presented across four themes to ensure cohesion and alignment with the NAF (DCCAE, 2018a,b):

1. natural and cultural capital;
2. critical infrastructure;
3. water resources and flood risk management;
4. public health.

It is important to note that all nine sectors identified in Figure 1.3 are captured under these four themes (Table 1.1) and that the importance of cross-sector and thematic interactions and interdependencies should not be underestimated when carrying out a comprehensive risk assessment and an associated robust adaptation response.

A key element of CCRA development involves stakeholder engagement and stakeholder workshops were held to inform this work at national and local levels (in 2017 and 2018, respectively). These workshops aimed to discuss the topic of climate risk, collectively agree on risk assessment methodologies and identify priority risks through interactive approaches, including risk identification exercises. The outputs and discussions from the stakeholder workshops were used to increase awareness and familiarity with terminology, concepts, approaches and options.

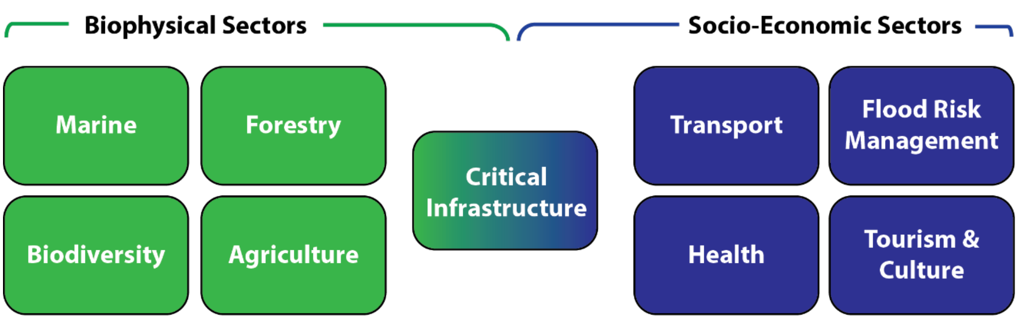

Figure 1.3. Ireland's nine key sectors, as identified in the NAF (DCCAE, 2018b).

Table 1.1. Themes and sectors considered as part of this work, in accordance with the NAF (2018)

Theme	Lead department	Sector
Natural and cultural capital	Department of Agriculture, Food and the Marine	Marine
		Agriculture
		Forestry
	Department of Culture, Heritage and the Gaeltacht	Biodiversity
		Built and archaeological heritage
	Department of Transport, Tourism and Sport	Tourism
Critical infrastructure	Department of Transport, Tourism and Sport	Transport infrastructure
	Department of Communications, Climate Action and Environment	Electricity and gas networks
		Communications networks
	Department of Housing, Planning and Local Government	Planning and development (including housing)
	Department of Agriculture, Food and the Marine, Office of Public Works	Coastal management
Water resources and flood risk management	Office of Public Works	Flood risk management
	Department of Housing, Planning and Local Government	Water quality
		Water services infrastructure
Public health	Department of Health	Health and well-being

The themed approach builds on efforts across government departments to identify synergies and efficiencies to increase coherence between respective climate policies and measures. The themes are cross-cutting in nature and therefore encourage the identification of interdependencies across sectors and government departments (see Table 1.1).

1.3 A Tiered Risk Assessment

Structures for evaluating climate change risk are important components of adaptation decision-making. This study applied an accessible, cost-effective and user-tested three-tiered CCRA framework created by the Australian National Climate Change Adaptation Research Facility (NCCARF, 2016). This iterative tiered assessment process also reflects the UK CCRA approach (HM Government, 2017). The tiered process consists of a sequence of consecutive climate risk assessment passes.

A first-pass assessment is a rapid qualitative process that can be carried out without detailed local data to develop a preliminary understanding of the climate change risks over a range of scales, from local to regional. This process helps users to screen climate-related hazards and identify specific risks that may arise from these hazards and which should be investigated further (through second- and third-pass risk assessments). This first-pass screening is ideal when carrying out a CCRA with resource constraints, including limited data and information. It also allows integration of data and information from a variety of (qualitative and quantitative) sources. This is an important early step in climate adaptation planning. Table 1.2 clarifies the different characteristics and requirements of each of the three risk assessment tiers.

Usually, the initial first-pass risk assessment is conducted with limited project-specific data (NCCARF, 2016), instead using qualitative information, evidence from published literature and available data such as default national figures. The outcome of a first-pass risk assessment provides a broad understanding of the impacts of climate change in a specific context (be that a region, sector or business). The clarity and accuracy of the analysis are tied to the level of detail provided. The assessment of adaptation responses to a risk involves (1) the identification of adaptation measures and (2) the evaluation of adaptation options. Only indicative costs are available at the outset and a decision is taken about whether or not to carry forward individual actions from a longlist to a shortlist for further examination. The first-pass assessment supports appropriate scoping and framing for further risk assessment and adaptation planning at a more detailed level (NCCARF, 2016; Tonmoy *et al.*, 2019). A second-pass risk assessment builds on the first-pass assessment by screening and building on the

Table 1.2. Tiered risk assessment characteristics and requirements

	First-pass risk assessment	Second-pass risk assessment	Third-pass risk assessment
Objective	Develop a quick high-level understanding of climate change risk to determine whether or not further research or adaptation planning is required at this time	Conduct a risk assessment (generally involving expert judgement) to identify specific risks that may become problematic under future climate change	Understand the vulnerability of different systems exposed to climate change-related hazards using more detailed and finer scale data; conduct a detailed risk assessment (quantitative or qualitative) to identify specific risks of different systems
Time and resource requirement	Minimum	Moderate	High
Data requirement	Nationally available datasets, which may be in published sources (e.g. summary regional projections and/or visualisations of climate and sea level variables). Available localised mapping and information. Data should be available at no cost	Nationally available climate change datasets, both observed and projected (e.g. from national meteorological centres), together with existing information available from government (e.g. local municipality) studies and/or expert knowledge. Data should be available at no or low cost	Some site-specific data (depending on the objective of the assessment and may not be necessary every time), e.g. lidar (light detection and ranging) data, in conjunction with high-resolution (daily, spatially explicit) climate scenario data and local expert knowledge to understand the exact scale of the risk. A substantial cost may be involved
Base knowledge requirement	• Minimum expertise required to acquire data • Local knowledge required to interpret data • Some understanding of climate change and its potential risks (readily available in many decision support tools such as Climate Ireland)	• Moderate knowledge required to acquire appropriate data • Moderate expertise required to interpret data • Moderate expertise required to understand the consequences of a specific climate risk	• High level of expertise required to acquire site-specific data (may not be necessary for all assessments) • High level of expertise required to apply data and analyse and interpret results • High level of expertise required to understand how a given climate risk can translate into a number of consequences for business
When should it be used?	• To develop a quick and broad understanding of climate change risk • To identify a need for strategic and ongoing responses/ commitments • To identify key localities for attention • To build awareness of risk among community and senior management • To seek a social and organisational licence to act on adaptation	• To develop a more detailed understanding of climate change risk and opportunities for a community or organisation • To identify key risk localities with follow-up resourcing requirements (e.g. new data, new study) • To get buy-in from community or senior management for developing an adaptation strategy or plan • To produce targeted climate risk communication materials • To identify adaptation options and support development of a plan or strategy	• To produce detailed impact studies of climate change effects on specific installations and activities, with a full understanding of the probabilities and uncertainties involved • To estimate the costs of adaptation action and prioritise resource allocation • To confirm emergency response procedures/requirements • To develop strategic and economic evaluations of adaptation options • To develop adaptation action plans for specific issues, including supporting detailed design
Limitations	Based on high-level screening and therefore not suitable for making any final decisions on adaptation actions	Based primarily on qualitative expert judgement of risk and therefore the results are as good as the qualitative judgement of the experts	Resource and time intensive, therefore requires expert input

Source: adapted from Tonmoy *et al.* (2019).

identified (first-pass) climate risks through engagement with experts with deep domain-specific knowledge, including local on-the-ground knowledge. The third-pass assessment process focuses in on specific areas of concern and uses quantitative and qualitative methods to generate detailed risk assessments (see Chapter 4 for case study application).

This research project aimed to generate a risk assessment working within the constraints of the available information, time and resources. The tiered assessment framework was employed as a tool to help realise this task. The result is a risk assessment that captures the range of risks posed by climate change (first pass) and further assesses priority risks through second- and third-pass assessment case studies.

This report therefore aimed to:

- provide a summary overview assessment of climate change risks across the four identified themes;
- frame risk assessment in the context of adaptation action;
- provide two worked examples of the application of risk assessment in greater detail.

The report is targeted at policymakers and practitioners working in climate change adaptation and climate risk management in Ireland. Local authorities and Climate Action Regional Offices (CAROs) may find its contents particularly informative. The overarching message of the report is that the quality of risk assessments is highly dependent on the quality of the data and analysis available to inform them. The quality of the analysis reflects the combined experience of the people involved, as well as the strengths of the tools available. CCRA is an iterative and ongoing process that demands significant investments of time, expertise and financial resources. These constraints, however, do not provide an reason for inaction. By engaging in a tiered assessment approach (as detailed in section 1.3) a CCRA can initially develop a high-level understanding of climate risks across society and then move to identify specific risks that may be problematic under climate change, before using more detailed data and analysis to conduct a detailed risk assessment, exploring specific risks in different systems. The authors also argue that the hard separation of risk from adaptation is viewed as less valuable than integrating the two, as CCRAs not only inform adaptation actions but also are dependent on the levels of current or planned adaption (taking into account existing adaptive capacity, for example).

1.4 Current and Projected Climate Conditions

Warming of the global climate system is unequivocal and it is extremely likely that human influence has been the dominant cause of observed warming since the mid-20th century. Observations show that average global temperatures have increased by 0.85°C (range 0.65–1.06°C) since 1850 (IPCC, 2013, 2018). The atmosphere and oceans have warmed, the volume of snow and ice has diminished and the sea level has risen as the concentrations of greenhouse gases (GHGs) in the atmosphere have increased (IPCC, 2013). The impacts are observed on natural and human systems on all continents and across the oceans (IPCC, 2014). Projections of future global and regional climate change under all IPCC representative concentration pathways (RCPs) demonstrate that continued emissions of GHGs will cause further warming and changes in the components of the climate system (Figure 1.4) (IPCC, 2013).

Projected SLR indicates that coastal systems and low-lying areas will increasingly experience adverse impacts such as inundation, coastal flooding and coastal erosion and accretion. The population and assets projected to be exposed to risks, as well as human pressures on coastal ecosystems, will increase significantly in the coming decades as a result of population growth, economic development and urbanisation (IPCC, 2014).

Projected increases in extreme high coastal water levels in Europe are likely to mostly be the result of increases in local relative mean sea level in most locations. Recent studies suggest, however, that increases in storm activity can also play a substantial role, in particular along the northern European coastline (IPCC, 2018, 2019). Projected SLR, possible changes in the frequency and intensity of storm surges, and the resulting coastal inundation and erosion are expected to cause significant ecological damage, economic loss and other societal problems along low-lying coastal areas across Europe unless additional adaptation measures are implemented (EEA, 2017). Climate change is also expected to result in an increased frequency and intensity of

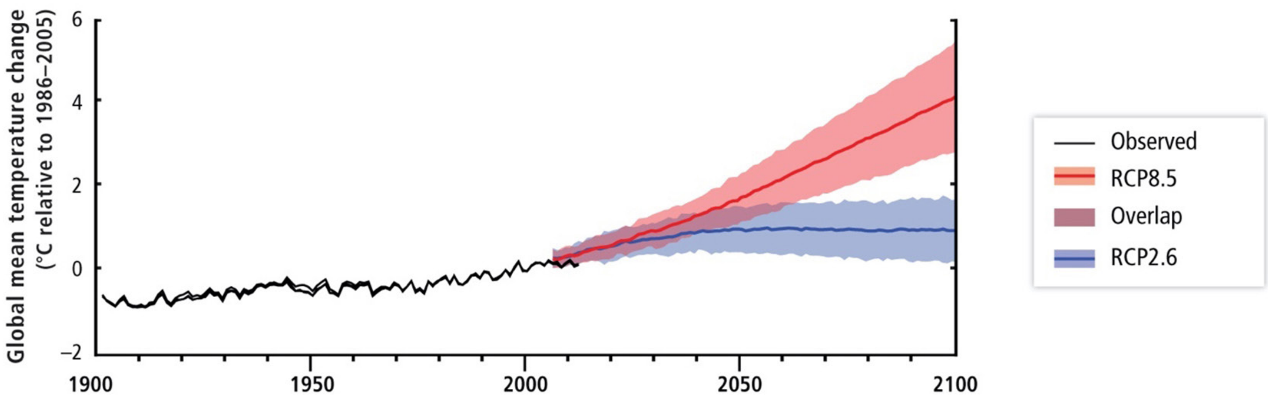

Figure 1.4. Historical and projected global average surface temperature change. Source: IPCC (2014).

extreme weather events, with potentially devastating consequences (IPCC, 2013). Extreme events such as severe flooding, droughts and heatwaves and cold waves are predicted to have cascading biophysical and socio-economic consequences at a variety of scales, including national and local.

Changes in Ireland's climate are in line with and similar to relevant global trends (Figure 1.5). Temperatures have increased by 0.8°C between 1900 and 2011, an average of 0.07°C per decade over this period (Dwyer, 2012). Projections indicate that this warming is expected to continue and increase by ~1.7°C by mid-century compared with the period from 1981 to 2000 (Nolan, 2015). For precipitation, observations indicate that average levels of national rainfall have increased by approximately 60 mm (5%) for the period from 1981 to 2010 compared with the period from 1961 to 1990. In contrast, projections of annual spring and summer average precipitation suggest an overall reduction by mid-century. For winter and spring, projections indicate an increase in overall levels of precipitation (Nolan, 2015).

Satellite observations indicate that the sea level around Ireland has risen by approximately 0.04–0.06 m since the early 1990s (EEA, 2012a; Flood and Sweeney, 2012). Measurements obtained from the tide gauge situated at Newlyn in Cornwall, UK, reflective of the situation in the south of Ireland, confirm this trend, indicating a mean SLR of ~1.7 mm per annum for the period from 1916 to 2012 (Dwyer, 2012). Sea levels are projected to continue to rise by up to 1.1 m by the end of the century relative to today's levels (IPCC, 2019). This figure may also be significantly larger based on more recent scientific findings that capture climate system feedbacks and interactions more completely than previous work (IPCC, 2019; Kulp and Strauss, 2019). Estimates of land inundation impacts on the Irish coastline indicate that approximately 350 km^2 of land is vulnerable under a 1-m SLR, rising to 600 km^2 for a 3-m SLR (Devoy, 2008; Flood and Sweeney, 2012).

These changes will have diverse and wide-ranging impacts, both negative and positive, on managed and natural ecosystems, water resources, agriculture and food security, human health and critical infrastructure in Ireland (Coll and Sweeney, 2013; Desmond *et al*., 2017). Changes in precipitation patterns are likely to lead to increased risks of flooding and water shortages (Bastola *et al*., 2011; Hall *et al*., 2012). Increasing temperatures will result in shifts in the growing season (Donnelly and O'Neill, 2013) and changes in the distribution of agricultural crops and disease vectors (Newton *et al*., 2012). Projected temperature increases could have severe implications for habitats and species, with profound effects on our ability to conserve species and habitats on which they depend (Coll *et al*., 2012). Rising sea levels will result in increased coastal inundation and erosion when combined with potential increases in levels of storminess and the increased risk of storm surges (Flood and Sweeney, 2012).

However, opportunities do exist for Ireland's key economic sectors. Increasing temperatures and drier summers will be likely to prolong the duration of the present peak tourism season into April and September/October and allow for a diversification of tourism activities, including the development of outdoor activities and the expansion of nature-based activities (Kelly and Stack, 2009; Salmon, 2010). Increasing temperatures and atmospheric concentration of CO_2

Hazards	Observed	Projected
Temperature	Average temperatures have increased by 0.8˚C since 1900, an average of 0.07˚C per decade The number of warm days (over 20˚C) has increased while the number of cold days (below 0˚C) has decreased	Projections indicate an increase in average temperature across all seasons (0.9-1.7˚C) The number of warm days is expected to increase and heat waves are expected to occur more frequently
Precipitation	Increases in average annual rainfall of approximately 60mm or 5% in the period 1981-2010 compared to the 30 year period 1961-1990 The largest increase are observed over the west of the country	Significant reductions are expected in average levels of annual, spring and summer rainfall Projections indicate a substantial increase in the frequency of heavy precipitation events in winter and autumn (approx. 20%)
Wind Speed and Storms	No long term changes in average wind speed or direction can be determined with confidence	An overall decrease in wind speed and an increase in extreme wind speeds, particularly during winter The number of very intense storms is projected to increase over the North Atlantic region. Projections suggest that the winter tracks of these storms may extend further south and over Ireland more often
Sea Level and Sea Surface Temperature	Sea level has not been measured with the accuracy to determine sea level changes around Ireland. Measurements from Newlyn, England, show a sea level rise of 1.7cm per decade since 1916. These measurements are considered to be representative of the South of Ireland. Sea surface temperatures have increased by 0.85˚C since 1950, with 2007 the warmest year in Irish coastal records	Sea levels will continue to rise for all coastal areas, by 1.1m by 2100. The south of Ireland will likely feel the impacts of these rises first. Sea surface temperatures are projected to continue warming for the coming decades. For the Irish Sea, projections indicate a warming of 1.9˚C by the end of the century

Figure 1.5. Irish climatic hazards with observed and projected impacts. Source: adapted from the NAF (DCCAE, 2018b).

may result in increased autumn and spring grass yields, which will allow livestock farms to increase their profits (Teagasc, 2010). It is also likely that the adverse impacts of climate change experienced elsewhere may create new market opportunities for Irish agriculture (RIA, 2003; IPCC, 2014, 2018, 2019). Moreover, there are wider opportunities arising from climate change that apply across all sectors. For example, water-sensitive urban design can provide an intrinsically greener, more pleasant cityscape than existing norms, and citizen engagement should be a key part of this new approach.

1.5 Summary of Irish Climate Policy and Governance

In 2009, the European Commission published the White Paper *Adapting to Climate Change: Towards a European Framework for Action* (EC, 2009). As a direct response, the Department of the Environment, Community and Local Government developed a National Climate Change Adaptation Framework in 2012 (DECLG, 2012). This marked the first step in the development of a comprehensive national policy position designed to allow planning to address the impacts of climate change. This non-statutory framework mandated the development and implementation of sectoral adaptation plans and local authority adaptation strategies.

European climate change adaptation policy was formalised in 2013 with the publication of the European Union (EU) Strategy on Adaptation to Climate Change (EC, 2013). This strategy promotes the three key objectives of (1) promoting action by Member States; (2) "climate proofing" action at EU level; and (3) enabling better-informed decision-making. The adaptation strategy is an important landmark in setting out the general scope for climate change adaptation in the EU (Biesbroek and Swart, 2019).

Across Europe significant variations in climate impacts, as well as governance complexities, make the EU's task of governing adaptation challenging (Biesbroek and Swart, 2019). For example, climate impacts in the Mediterranean region centre on increasing droughts, decreasing crop yields, expansion of infectious diseases and forest fires. Increased fluvial (or riverine) flooding is where impacts will be felt most in central Europe (EEA, 2017). In Ireland, impacts are focused on coastal erosion, and inland and coastal flooding (Dwyer, 2012; IPCC, 2013).

Irish climate adaptation policy was restated in the National Policy Position on Climate Action and Low Carbon Development, published in April 2014 (DCCAE, 2014). The National Policy Position provided a high-level policy direction for the adoption and implementation of plans to respond to climate change through mitigation and adaptation. Statutory authority for these plans was subsequently provided for in the Climate Action and Low Carbon Development Act 2015 (DCCAE, 2015a) (Figure 1.6).

Through the 2015 Climate Act, Ireland's climate policy framework is designed to deliver the overall vision of a transition to a carbon-neutral, low-emission and climate-resilient society and economy by 2050. This is to be achieved through a series of National Mitigation Plans and the NAF. The NAF, published in 2018, provides a strategic policy focus to ensure that adaptation measures are taken across all sectors and levels of governance to increase Ireland's preparedness for, and reduce vulnerability to, the now inevitable impacts of climate change (DCCAE, 2018b). In addition to considering Ireland's response to shorter term impacts of climate change, the NAF seeks to build long-term[1] resilience to climate change impacts through adaptation planning. As sectors and local authorities in Ireland develop adaptation plans and strategies, as mandated by the NAF, a coherent and measurable approach to climate resilience is necessary. This needs to be underpinned by an understanding of climate risks.

The NAF places a statutory requirement on government departments to develop adaptation strategies for the key sectors of the Irish economy and on local authorities to develop local-level adaptation strategies. To support the development of these strategies, *Local Authority Adaptation Strategy Development Guidelines* (DCCAE, 2018c) and

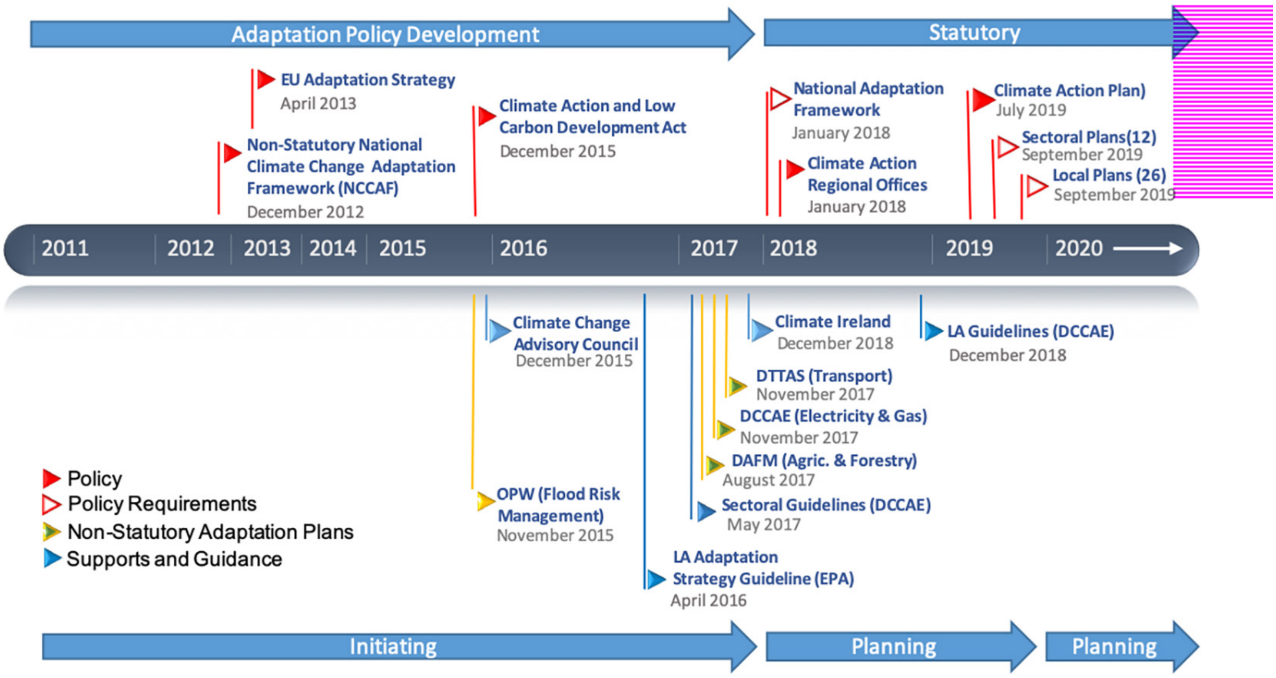

Figure 1.6. Evolution of Irish climate policy. DAFM, Department of Agriculture, Food and the Marine; DCCAE, Department of Communications, Climate Action and Environment; DTTAS, Department of Transport, Tourism and Sport; EPA, Environmental Protection Agency; OPW, Office of Public Works.

1 When considering the immediacy of climate risks, the following timescales are employed in this report: short (<5 years), short to medium (6–20 years), medium to long (21–50 years) and long (>50 years).

Sectoral Planning Guidelines for Climate Change Adaptation (DCCAE, 2018a) have been put in place, in addition to web-based support through the Climate Ireland Platform (which commenced development in 2011; Climate Ireland, 2020).

The Irish Climate Change Advisory Council (CCAC), established under the Climate Action and Low Carbon Development Act 2015, is the independent body tasked with assessing, and advising on, how Ireland is to make the transition to a low-carbon, climate-resilient and environmentally friendly economy. Similar to the UK's Committee on Climate Change, the CCAC provides contributions in the form of critiquing, informing and shaping Ireland's response to climate change (CCAC, 2019).

In 2018, under Ireland's NAF, funding of €10 million was provided by the Department of Communications, Climate Action and Environment (DCCAE) over 5 years to establish local authority CAROs. The CAROs are tasked with supporting and implementing national climate policy and their establishment further acknowledges the important role that local authorities (local government) play in planning for and implementing climate adaptation actions. These offices are intended to enable more co-ordinated engagement across the whole of government, providing for vertical and horizontal integration of adaptation considerations.

In June 2019, the Climate Action Plan (Government of Ireland, 2019) set out a series of actions to achieve adaptation and mitigation targets, in line with the EU's goal to achieve net zero carbon emissions by 2050. The government aims to use the plan (and its subsequent annual plans) to define a roadmap for climate resilience through initiating, monitoring, and reviewing and revising a coherent set of fit-for-purpose policy actions. It should be noted that the plan is to be revised and updated each year to track climate action progress.

The plan includes a number of key features:

- a 5-year carbon budget and sectoral targets, with a detailed plan of actions to deliver them;
- a Climate Action Delivery Board overseen by the Department of the Taoiseach to ensure delivery;
- an independent CCAC to recommend the carbon budget and evaluate policy;
- strong accountability to an Oireachtas Climate Action Committee;
- carbon proofing of all government decisions and major investments.

Climate adaptation plans are captured in the plan under three specific actions:

1. build sectoral resilience to the impacts of climate change through delivery of sectoral plans, as required under the NAF (Action 181);
2. build local/regional resilience to the impacts of climate change through delivery of local authority adaptation strategies, as required under the NAF (Action 182);
3. put in place arrangements to ensure that Climate Ireland is developed to its full potential as an operational support for climate adaptation and climate action in Ireland (Action 183).

Furthermore, the 2019 Climate Action Plan recalls the statutory obligations related to adaptation in the Climate Act and creates a new mandate for government departments to develop decarbonisation strategies that will complement these adaptation plans. It states that "Climate proofing Ireland is a collective responsibility for which every member of Irish society is responsible" (Government of Ireland, 2019, p. 145). Mainstreaming of adaptation is further supported at the regional level through the four CAROs, established in 2018. The CAROs aim to integrate local and sectoral adaptation priorities and harness the potential of grouping local authorities based on their geographical location and similar climatic characteristics (e.g. similar threats and opportunities) to develop regionally focused adaptation planning frameworks in support of co-ordinated local-scale adaptation planning.

It is useful to note the relevance of the National Planning Framework to climate policy development and implementation (Government of Ireland, 2018). In summary, the National Planning Framework provides a guide to the future development of Ireland, taking into account a projected 1 million increase in our population up to 2040. The plan includes 10 National Strategic Outcomes, including transition to a low-carbon and climate-resilient society (National Strategic Outcome 8).

The planning process provides an established means through which climate change adaptation objectives can be integrated and implemented at local level (DCCAE, 2018b,c). Planning legislation already requires different levels of the planning process to address climate change. The National Planning Framework represents a key opportunity to ensure that the climate implications of spatial choices are fully considered and addressed from the top of the planning hierarchy. Climate projections and risks that inform such implications must be core considerations within all plans and strategies developed within this hierarchy. The draft National Planning Framework includes an objective to support national targets for emissions reduction and objectives for climate change mitigation and adaptation by ensuring that climate change considerations are further integrated into the planning system and that they continue to be taken into account as a matter of course in planning-related decision-making processes. The issue of planning is covered in greater detail under the theme of critical infrastructure (see section 3.2.2).

1.6 Report Layout

This CCRA required the employment of a number of methods and approaches, which are detailed in Chapter 2. Chapter 3 documents the findings of the project's thematic risk assessment. The assessment covers the risks and impacts of climate change for Ireland's environment, economy and society and identifies priority risks for further analysis where there are clear gaps in the sectors and themes. The results of the assessment are presented across four themes (covering nine sectors) to ensure cohesion and alignment with the NAF (DCCAE, 2018a,b). Chapter 4 examines the data needs and presents case study application examples of exposure to urban heat in Dublin City and SLR and economic costs. Finally, Chapter 5 provides concluding remarks and recommendations.

2 Understanding Risks and Evaluating Adaptation Options

2.1 Introduction

This chapter sets out the interlinked methods required for a CCRA under the follow headings:

- identifying and assessing climate risk;
- appropriate responses to risk;
- adaptation pathways;
- evaluation methods;
- evaluating adaptation options; and
- mainstreaming.

2.2 Identifying and Assessing Climate Risk

At the outset it is important to provide a rationale as to why it is important to map climate risk. CCRAs enable (limited) resources from a common "pot" to be prioritised across different areas. CCRAs provide a sound basis for (1) making decisions on whether or not risks, and what level of those risks, are acceptable to society or a community and (2) obtaining, collating and analysing information on how risks deemed unacceptable can be reduced to below thresholds of acceptability and how potential opportunities can be realised. Risk is defined by assessing exposure to a weather and climate event (hazard) and measuring the vulnerability of the exposed asset or system to that hazard. To capture a measure of vulnerability one needs to capture or estimate the losses and damages associated with the impacts arising from exposure to any given hazard. A CCRA must go beyond measuring changes to the nature, magnitude and frequency of climate and weather events. It must aim to capture and describe the short-, medium- and long-term risks to social, environmental and economic conditions as a result of these impacts and provide adaptation options and trade-offs to present a range of least-cost adaptation actions.

The quality of outputs produced by any CCRA is highly dependent on the quality of the data inputs. It is important to note that "data" has connotations of hard, simple, measured, narrow information, and a robust CCRA needs to consider the full range of evidence, which can take many forms, including anecdotal accounts of past events. Furthermore, when looking in detail at any one place, local "informal" knowledge will be equally important (and probably more immediately meaningful) as "hard" data. Moreover, while individual datasets can display important messages about individual risks, a CCRA must endeavour to combine data in order to examine cumulative impacts. Identifying reliable sources of verified data is a vital first step. Complex decisions, such as allocating land to development or evaluating aspects of risk in particular geographical areas, require information and tools to aid in understanding the inherent trade-offs.

They also require mechanisms for incorporating and documenting the value judgements of a range of stakeholders, including communities, non-governmental organisations, environmental non-governmental organisations, technical experts and the private sector, into the decision-making outcomes. Geographical Information Systems (GIS) data can form the basis of an initial risk-identifying exercise. Several data-driven decisions need to be made during such an exercise. These include:

- The types of data that could be used in the analysis:
  - Are the data from a reputable and legitimate source?
  - Are datasets compatible in terms of scale, calibration and geo-reference?
  - Will trends over time be captured?
  - What assumptions were made when the data were generated and collated?
- The representation of data:
  - How will uncertainty be accounted for?
  - Will the data be comparable at global or national levels?
- The resolution of the data:
  - What is the best scale to display the data?

Broadly speaking, data can be categorised as social, economic or environmental (including observed and projected biophysical data). The measurement of social vulnerability identifies population characteristics that influence the differentiated social burden of risks and how these factors impact on the distribution of potential losses. Social vulnerability is most often described using individual characteristics of people (age, race, health, income, education) but also includes place inequalities – those characteristics of communities and the built environment, such as the level of urbanisation, growth rates and economic conditions, that contribute to the social vulnerability of places. While numerous composite indices of social vulnerability (which need to be broken down carefully if they are to be easily understood and be fit for purpose) have been used around the world, most have common elements, such as population structure and education levels, that are collected during census exercises (Klein *et al*., 2014; Kopke *et al*., 2016; IPCC, 2018). Economic data can refer to macro- or microeconomic conditions.

Climate Change Risk Assessments often draw on economic data on the built environment. These data can include information on housing, infrastructure systems, critical facilities and cultural resources. Critical public assets are those that are essential for supporting the function of the economy and society as a whole. Examples include power plants, road and rail networks, hospitals, schools and water supply infrastructure. Understanding the location and density of critical assets is the first step in determining exposure and associated site-specific risks. For example, the density of privately held assets, such as residential properties, provides a key measure of population distribution, which often correlates with critical asset density. Measures of critical asset density can in turn be used to predict the economic impact of extreme weather events such as large storms or floods.

Environmental information, such as land cover data, enables communities to track changes in their environment over time, as well as identify possible conflicts between land uses, for example competing interests associated with building residential housing and protecting biodiversity and natural landscapes. Land cover data can show, on a local scale, how man-made surfaces, agricultural lands and ecological systems are changing and interacting. Land cover maps are used widely by public bodies, researchers, scientists and private companies for a range of applications, including water management, air quality management, land planning, waste management and agriculture/forestry management. In addition, Natural Heritage Areas (NHAs), Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) can be captured. Data related to gradual changes in the climate and environmental conditions, as well as impacts of extreme weather events, can also be captured through mapping of environmental information. These data may include information on changing coastlines (driven by coastal erosion), changes in temperature and precipitation patterns, the footprint of coastal and inland flooding, and storm events.

2.3 Appropriate Response to Risk

Adaptation for future climate change involves a mixture of response strategies and actions that are complementary, location specific and proportionate to the risk. Expert knowledge, local knowledge, stakeholder involvement and literature reviews are promoted as methods to identify the appropriate mix of adaptation measures. De Bruin *et al*. (2009) carried out an inventory and ranking of 96 adaptation options for the Netherlands based on stakeholder consultation, expert judgement and some indicative costs ranking. However, a systematic method to identify adaptation options in response to climate change risks is lacking in most countries (Carter and Mäkinen, 2011). The outcome may be that an incomplete list of adaptation options is put forward for evaluation, a cluster of similar options are compared or a predetermined solution is justified. Generating a longlist of options at the start of the appraisal process ensures that a range of adaptation types is considered (HM Treasury, 2018). Information on identifying, assessing and prioritising adaptation options is available on the Climate Ireland website (www.climateireland.ie). Furthermore, there is a need to acknowledge the importance of ensuring that risk, as a separate metric, is firmly embedded in adaptation decision-making, using Climate Ireland as the information platform to achieve this.

One approach to generate a comprehensive longlist is to purposely identify different types of options under a classification system. Adaptation actions have been classified according to high-level features, e.g. hard, soft, transformative and incremental used by the World Resources Institute (WRI, 2009) and grey, soft and green used by the European Environmental Agency (EEA, 2013). The latter classification is also used in the NAF (DCCAE, 2018b). Grey adaptation measures involve technical or engineering solutions to climate impacts; examples include the construction of sea walls and tidal barrages (EEA, 2013). However, adaptation is not limited to hard engineering projects such as the construction of dams and sea walls designed to cope with climate change and variability (Callaway *et al*., 1998; EEA, 2016). Soft adaptation is also a key component of climate change adaptation and involves alterations in behaviour, regulations or systems of management; examples include extending time frames of plans further into the future, zoning development away from sensitive areas, and instituting or strengthening building codes in hazard-prone areas. Soft planning includes behavioural adjustments that households, firms and institutions make in response to the direct effects (flooding, heat) and the indirect effects (energy and food prices) of climate change, and adjustments made in response to educational and promotional campaigns (Leary, 1999; Klein *et al*., 2014; EEA, 2016). These may result from policy nudges (behavioural economics) or market forces, e.g. risk-adjusted insurance rates. Green adaptation measures seek to utilise ecological properties to enhance the resilience of human and natural systems to climate change impacts. An example is the re-establishment of dune systems to act as buffers against coastal storms. In effect, some adaptations, such as urban greening or the extension of flood plains to accommodate river flooding, can be included under all four classifications, spanning a range from hard to soft solutions and from incremental to transformative changes.

Adaptation options can be mapped onto these groupings to ensure an expansive approach at the outset. Once a longlist is developed it can be filtered down to a set of viable shortlist options ahead of detailed economic analysis. Viable options are identified according to economic, social and environmental considerations. Shortlisting can include criteria such as strategic fit to wider policy objectives, potential value for money, affordability and achievability, agreement with legal frameworks and social acceptance (HM Treasury, 2018). An adaptation strategy should include measures that address the underlying local factors of vulnerability to climate change, such as economic vulnerability of the population, resource degradation and lack of information.

2.4 Adaptation Pathways

Aiming for responses proportionate to the risks and avoiding lock-in to one adaptive measure is not an easy task, and the adaptation pathway approach, introduced here, has been adopted in many countries for developing strategies under high levels of uncertainty, with long time frames and with competing calls on resources. No-regret options are measures or activities that will prove worthwhile even in the absence of further climate change. Low-regret options are no-regret options that require small additional outlays to cater to the negative effects of climate change (Niang-Diop and Bosch, 2004).

The adaptation pathway approach was pioneered in the UK by the Thames Estuary TE2100 project, which addressed the risks of SLR to the Thames Estuary (Reeder and Ranger, 2011). Figure 2.1 gives an example of an adaptation pathway approach to coastal risks from SLR.

Acknowledging that maintaining flexibility is the best approach to uncertainty, multiple pathways to achieve a policy objective are mapped out side by side. Each adaptation pathway consists of a series of actions with outcomes and resource requirements. Pathways act as a route map where a destination has been identified, but the steps taken to reach it remain flexible and responsive to new information and circumstances (Bullock *et al*., 2011). The actions are evaluated and re-evaluated, with methods including real option techniques and robust decision-making (RDM). Real option techniques are an extension of cost–benefit analysis that include the possible advantage of delaying a decision until more information is available and balancing the costs and benefits of delaying a decision (Fankhauser and Soare, 2013). The benefits depend on how much learning can take place over the delay time balanced against critical events that may occur during the delay time.

Robust decision-making is an approach that does not strive to make better predictions, but to yield better decisions under conditions of high uncertainty (Lempert, 2019). In RDM, long-term climate risk management seeks robust and resilient rather than optimal strategies. It must be noted that what may be optimal today may not be optimal tomorrow, and that what is optimal to one stakeholder may not be to others – so robust and resilient strategies are ones that can persist in the face of possible future

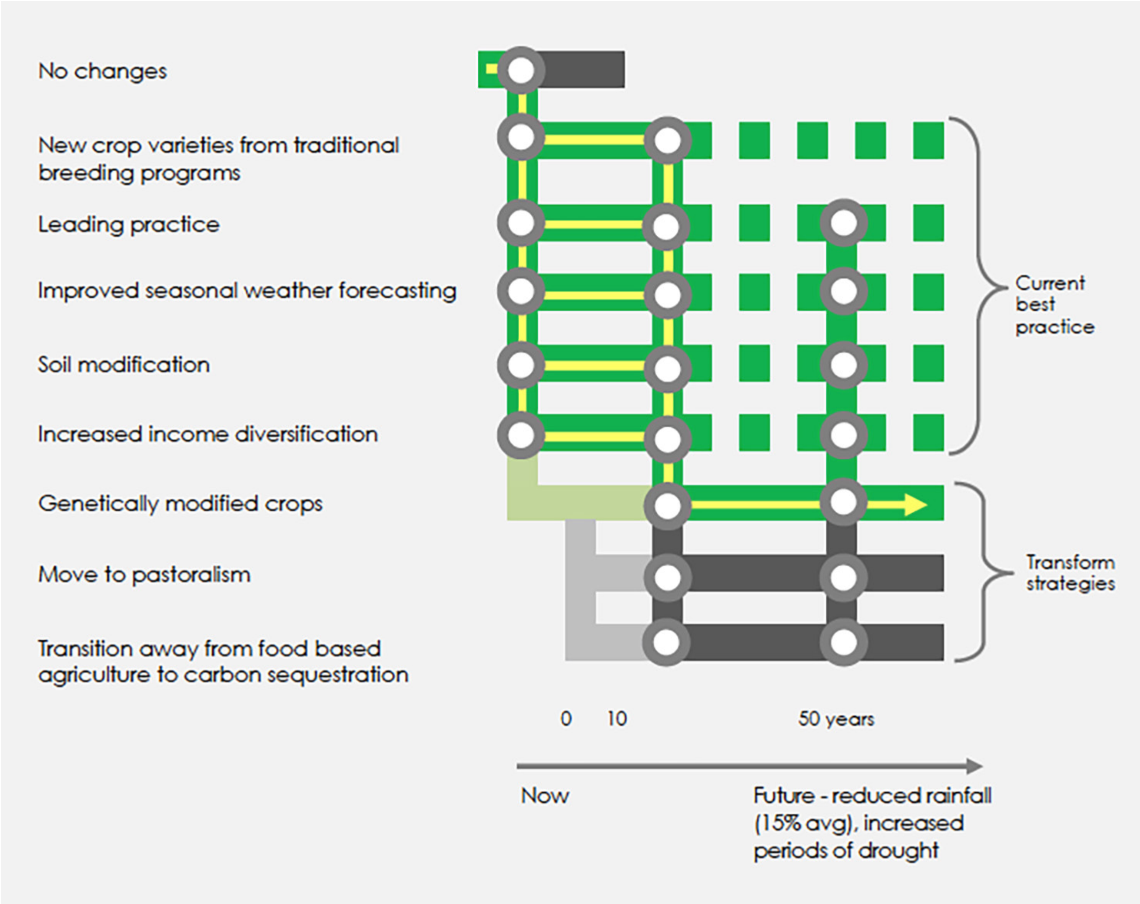

Figure 2.1. An example of an adaptation pathway examining the impacts of reduced precipitation on agriculture. The map identifies adaptation options on the *y*-axis. Trigger points occur along the *x*-axis, with the estimated time frames also noted. Source: adapted from Siebentritt *et al.* (2014).

uncertainty and secure the widest acceptance across society. The ability to predict future climate, economic and technological conditions is limited, and the optimal adaptation investment is known only in hindsight. RDM supports the identification of robust solutions capable of high levels of performance against a large number of futures, thereby enhancing the resilience of society against future hard-to-predict or hard-to-quantify risks. In practice, this means developing adaptation strategies that retain flexibility. Therefore, adaptation generally consists of near-term decisions that provide benefit even if assumptions about future climate conditions do not hold. Autonomous change is encouraged and large upfront sunk costs are avoided to prevent lock-in to one strategy (Watkiss and Hunt, 2012). The flexibility allows reassessment of adaptation options as information and/or new technology becomes available.

Iterative risk management and adaptive management is inherent in all approaches but is a key feature in the pathway approach (Table 2.1). Changing circumstances and new information can trigger a change in route by switching or adding actions to ultimately achieve the objective. Some pathways are more robust, while others are flexible. The ultimate choice depends on stakeholder preference and the resources available.

2.5 Evaluation Methods

National governments and agencies have an important role in promoting and providing climate change adaptation because of the presence of market failures that prevent adaptation occurring spontaneously (Bullock *et al.*, 2015). In Ireland, the Public Spending Code, provided by the Department of Public Expenditure and Reform (DPER, 2019), is a set of rules and procedures to ensure that the best possible value for money is obtained whenever public money is being spent or invested. The Public Spending Code includes financial analysis and economic analysis. The

Table 2.1. Adaptation pathways: a high-level framework for planning adaptation options

	Suited to	Used in	Uncertainty
Adaptation pathways	• Where there are clear risks and thresholds • Where a mix of quantitative and qualitative data needs to be considered	• Water and coastal management	• Deal explicitly with uncertainty by analysing the performance of adaptation for different potential futures
Real-options analysis	• The appraisal of large capital investment over the medium term • Where information on climate risk probabilities is available • When future changes in operation are possible	Few applications exist, but include: • construction • regional planning • energy • forestry • agriculture	• Deals explicitly with uncertainty by analysing the performance of adaptation for different potential futures
RDM	• The appraisal of investments over long timescales • Where large uncertainties exist • Where a mix of quantitative and qualitative information needs to be considered	• Water and coastal management • Agriculture • Energy • Health • Construction • Civil protection	• Deals explicitly with uncertainty • Analyses the performance of adaptation for different potential futures
Iterative risk management/ adaption management	• Policy appraisal over the medium to long term • When there are clear risk thresholds	• Water management • Coastal management • Agriculture • Health • Forestry	• Deals explicitly with uncertainty • Promotes iterative analysis, monitoring, evaluation and learning
No-regret options	• Measures or activities that will prove worthwhile even in the absence of further climate change	• Water and coastal management • Agriculture • Energy • Health • Construction • Civil protection	• Initial steps while risk is evaluated
Low-regret options	• Measures require small additional outlays to cater to the negative effects of climate change	• Water and coastal management • Agriculture • Energy • Health • Construction • Civil protection	• Initial steps while risk is evaluated

Source: adapted from ECONADAPT (2019).

latter considers socio-economic and social acceptance aspects of the proposed action.

Cost–benefit analysis (CBA) is an accounting tool used extensively by businesses and groups to systematically determine the best use of resources. In addition to CBA, a range of decision support tools is used to support project and policy evaluation. The most common methods, and their pros and cons, are summarised in Table 2.2. A broad appraisal framework will incorporate a number of the different tools over different time frames. In this section, CBA is briefly reviewed and some of the different assessment methods are introduced to see how they address some of the challenges associated with CBA (see Table 2.2).

Cost–benefit analysis is a financial accounting tool that determines if the benefits of an action exceed the

Table 2.2. Methods used to support adaptation decision-making and how uncertainty is addressed in each

Method	Suited to	Used in	Uncertainty
CBA	• Low- and no-regret options in the near future • Hard engineering projects where clear market values can be used	• Agriculture • Forestry • Energy • Water and coastal management • Transport	• Does not explicitly deal with uncertainty but can be combined with sensitivity testing and probabilistic modelling • Valuation of intangibles difficult • Issues such as equity and affordability assessed separately
Cost-effectiveness analysis	• Short-term adaptation • Where benefits should be examined in non-monetary terms • Where pre-defined objectives must be achieved	• Health • Civil protection • Biodiversity protection	• Does not explicitly deal with uncertainty • Can be combined with sensitivity testing and probabilistic modelling
Multi-criteria analysis	• Scoping options, i.e. evaluating an initial longlist of potential actions • Where a mix of quantitative and qualitative data needs to be considered	• Water and coastal management • Agriculture • Biodiversity protection	• Can integrate uncertainty as an assessment criterion • Relies on subjective expert judgement or stakeholder opinion
Portfolio analysis	• When a number of complementary adaptation actions are possible • When good economic and climate information exist	Few applications, but these include: • water and coastal management • forestry • health • fisheries • agriculture • biodiversity protection	• Deals explicitly with uncertainty • Examines the complementarity of adaptation options for dealing with future climates

Source: adapted from ECONADAPT (2019).

costs in present value terms. CBA is routinely used to assist in policy formulation (Cahill and O'Connell, 2018). CBA incorporates all of the benefits and costs to society, in monetary terms, for each option to produce a net benefit for each option.

The basic cost–benefit formula determines that if:

- the benefit-to-cost ratio is < 1.0, the costs exceed the benefits in economic terms;
- the benefit-to-cost ratio is > 1.0, the benefits exceed the costs in economic terms.

All project costs incurred must be included: planning, surveys, preliminary engineering and project design, as well as labour, land and materials for construction. CBA is used to evaluate different policy options and compare choices using a benefit-to-cost ratio. The net benefit of each option is then compared. The "best" project is the one that maximises the expected net present value of costs and benefits. A project with a negative net benefit is unlikely to proceed.

2.5.1 Cost–benefit analysis

A positive net benefit means a project has some merit but it will be competing for limited government financial resources. Affordability and value for money are determined separately from the CBA. A single CBA will not carry through an entire project as price movements occur within the evaluation and lifetime of a project and more information becomes available over time. Gathering good data takes time and can impose onerous staffing requirements. Market values for all parameters are needed to obtain quality results. CBA can be used as a component criterion within other evaluation methods, such as multi-criteria analysis (MCA) and adaptation pathways. The Public Spending Code strongly suggests using CBA for economic analysis where non-market societal net costs/benefits (welfare losses/gains) are included. Counterfactual scenarios are evaluated to estimate the level of private investment that could be forthcoming in the absence of proceeding with a project.

The challenges associated with CBA are not unique for adaptation action appraisals but can be exacerbated in this context; the United Nations Framework Convention on Climate Change (UNFCCC, 2011) groups the issues under three themes: uncertainty, valuation and equity. CBA has always dealt with uncertainty regarding future socio-economic and technological development, with sensitivity analysis applied by adjusting key parameters in the model. The inclusion of climate change uncertainties in the model of climate change scenarios complicates the analysis further. A modified discount rate and/or time frame for climate change projects could capture climate change adaptation planning concerns. A discount rate is applied to enable valuation of costs and benefits at the present time value. Costs are more attractive the further in the future they will actually be incurred. Benefits, on the other hand, are preferred immediately. There is considerable debate among economists about the rate at which these future costs and benefits should be discounted (Arrow *et al*., 2013; Cahill and O'Connell, 2018). Lowering the discount rate, using a social discount rate or changing the discount rate over time could stimulate investment in risk reduction, although the benefits would be accrued in the future. In Ireland, the rate in the Public Spending Code is 4%. Cahill and O'Connell (2018) have suggested that the discount rate could be modified for adaptation/risk reduction projects. The time frame used in the analysis also impacts on net present values. A modified time horizon may be permissible for projects with very long-term impacts (DPER, 2019).

The UNFCCC (2011) distinguishes between financial assessments that consider financial costs and benefits only and economic assessments that consider the wider costs and benefits to the national economy, e.g. welfare analysis, and to the environment, e.g. ecosystem services. Thaler *et al*. (2019) find that inclusion of intangible assets, such as socio-cultural values, in the assessment of adaptation options promotes acceptance of change by communities. Natural capital was defined as those elements of the natural environment that provide valuable goods and services to people. Economic and accounting methods for public and private assets were combined with the best natural science understanding so that natural capital was measured and accounted for in monetary terms. It is an approach that allows the impacts of climate change and adaptation investments on nature to be included in cost–benefit types of analysis. A methodology for valuing natural capital and ecosystem services within Ireland is being developed by the Irish Forum on Natural Capital.

The data requirements for CBA economic assessment are numerous. CBA is easier to apply to large engineering projects ("hard" infrastructure or equipment adaptation measures). These projects are easier to quantify than the "softer" adaptation measures described in section 2.3. CBA is not a good method to provide a business case for softer adaptation options (Agrawala and Fankhauser, 2008; Zhu and van Ierland, 2010), but these soft options may provide potentially critical adaptation measures and avoid inappropriate and costly adaptation measures. The incorporation of longer time frames associated with climate change, as well as wider costs and benefits, makes CBA more complex. However, mainstreaming climate change adaptation, as explained in section 2.7, would involve the modification of standard CBA for most publicly funded projects in order to properly consider the impacts of climate change, the uncertainty of climate scenarios, concurrent adaptation policies and long-term adaptation interventions and investments.

Economic analysis techniques have been further developed that (1) incorporate timescales that are longer than the usual return on investment and (2) incorporate the uncertainty in many of the projection variables (Agrawala and Fankhauser, 2008). Evaluation methods use climate change projections to calculate the probability of these costs occurring. In addition to costs, methods have been developed to incorporate other factors that are considered valuable by society, such as landscape and health. Value relates to importance, rather than just a monetary price (Gómez-Baggethun and Martín-López, 2015). The evaluation of climate risks and adaptation responses becomes a socio-economic exercise, particularly for decision-makers involved in public policy and public spending.

Methods used as decision support tools for planning for adaptation, needed because of uncertainty, valuation and equity issues, are elaborated on here. The technical complexity of the evaluation used will depend on where one is in the decision-making cycle and how much one needs to incorporate societal values into decision-making. Accounting-like Excel spreadsheets for CBA are familiar to most and many templates have been developed for assessing adaption plans (e.g. GIZ, 2013). Within the templates, key variables can be modified for sensitivity analysis. These types of analysis can be explained and shared – important when transparency is required. They can also be quickly updated as more information becomes available. More technical modelling is also used, especially when the variables are all quantitative and when many of the variables have uncertainty attached. Ryan and Stewart (2017) used a probabilistic model to determine the optimum power pole replacement schedule (for ESB Networks, for example) and to address the uncertainty and variability associated with many aspects of the model: infrastructure element deterioration, network maintenance and climate change effects.

2.5.2 Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) is a form of economic analysis that compares the relative costs of actions to achieve an objective. Unlike CBA, this type of analysis does not assign a monetary value to the outcome (benefit). A pre-determined outcome is decided and CEA is used to determine the least-cost routes to achieve the objective. This analysis is useful in situations in which it is difficult, controversial or inappropriate to calculate monetary values for the outcome, e.g. quality of life measures. Maximising the average effect per unit of investment is the aim, although different versions of CEA are used to address the distributional issues in the costs and effectiveness for different socio-economic groups.

The benefits of CEA are that it values non-market outcomes, it is easy to communicate and most evaluators will have experience of it. The drawbacks are that it normally does not incorporate uncertainty and one pre-defined outcome is considered. Therefore, it is recommended when not all costs and benefits can be expressed in monetary values for short-term planning and low- and no-regret options, rather than for cross-sectoral complex systems. As climate change accelerates, the scale of the response measures will increase accordingly, potentially involving wholescale changes to current practice. In this case, real-options analysis will become applicable to more and more sectors.

2.5.3 Multi-criteria analysis

Multi-criteria analysis is a multi-metric analysis that can encompass CBA and other economic considerations (impacts on economy and economic growth) plus non-monetary measures. MCA is a common tool in decision analysis when there are multiple options and multiple objectives. An MCA offers users the ability to rank and prioritise among multiple adaptation options. MCAs are most commonly used when not all benefits can be measured quantitatively or when multiple benefits cannot be aggregated. Unlike a CBA, the analysis can be based on qualitative criteria as well as economic factors. A problem is defined and a range of alternative solutions identified. A set of criteria is selected and the standardised scores and weights for each criterion are determined.

Project characteristics such as feasibility, equity and acceptability can be included in MCA. Implementation factors such as feasibility, cost-effectiveness (e.g. net benefits from CBA), co-benefits, ease of implementation and resources, which can often be hard to quantify, can be led as criteria (UNFCCC, 2011; GIZ, 2013). Choosing the appropriate weights for each criterion involves expert input and is very project specific. It may be desirable to set a minimum score for essential criteria. The MCA facilitates criteria selection and scoring from a range of perspectives, e.g. engineering, economist and ecology. MCAs can be used before full social CBA of the options has been conducted and, therefore, are very useful for initial scoping studies (such as first-pass assessments) to reduce the number of options going forward to more detailed analysis. The ranked options from the MCA approach provide a focus for policy dialogues with stakeholders that will be involved in, or affected by, future decisions. Ranking the adaptation options according to the "levels of regret" classification, as described in section 2.5, is another method of comparing options, i.e. rank according to the consequences of making a wrong decision. Applied criteria can include the degree of complexity, cost and risks for each option.

2.5.4 *Portfolio screening*

Portfolio screening for climate change was originally associated with developmental agencies screening their current and planned project portfolios for climate impacts (Klein *et al*., 2007) but is applicable to all agencies and national development planning.[2] Current and planned projects are analysed for climate adaptation impacts. Portfolio screening can achieve two things:

1. contribute to the climate proofing of existing projects – modifications to existing projects could avoid accidental maladaptation and/or provide improved resilience;
2. ensure that climate change is explicitly integrated into future projects and strategies at the outset by including priorities that are critical to successful adaptation.

2.6 Evaluating Adaptation Options

Adaptation to cope with climate change will require significant investment in Ireland. The NAF (2018) outlined that a national response to adaptation will need to be cross-sectoral and will probably have cost implications for various sectors. Available Exchequer monies for climate change adaptation in 2021–2030 will have to compete with parallel future mitigation and climate finance commitments, as well as other fiscal priorities. Economic analysis is a component of decision support tools used to quantify the costs and benefits of climate impacts and adaptation actions. Both public and private sectors need to build capacity to make well-informed choices about diverse adaptation options. Data, practical methods, tools and guidelines are required for these methods (Tonmoy *et al*., 2019). Current and changing socio-economic factors must be included.

Results-orientated programmes need to be clear on policy objectives and appraise a set of feasible alternative implementation options that would achieve the same objective(s). Inclusion of a structured economic analysis in the appraisal method helps identify the preferred option in relation to the best action to achieve outcome objectives and provides a priority-setting method for determining where and when the actions should be undertaken. Economic methods have been developed to assist with a wide range of issues that involve decision-making in the face of uncertainty (Heal and Millner, 2014). These methods have already been applied to the evaluation of risk reduction measures, such as decisions on which coastal areas to protect and how much to protect them. The EU ECONADAPT project classified situations that involve adaptation evaluation into five classifications: project appraisal, policy impact assessment, disaster risk management, macro-economic assessments and international development (ECONADAPT, 2019).

In the context of climate change impacts and alternative adaptation policy options, systematic assessment of adaptation options that are technically, economically and politically feasible is needed to enable planners to appraise alternative responses to climate change (de Bruin *et al*., 2009). Government and local authority budgets are limited and inclusion of economic analysis in adaptation appraisals can enhance the capacity of society to adapt. Economic analysis gives an indication of the present net value of different options under different possible scenarios (Nordhaus, 1992) and also allows the impact of actions on future generations to be considered. Economic analysis can uncover the trade-offs associated with different options in the medium to long term and provides transparency to stakeholders.

In addition, economic analysis, when coupled with projections of future climate and climate impacts, can identify the appropriate timing with regard to adaptation implementation. This can best be achieved through an adaptation pathway approach. Adaptation pathways are structured around key thresholds of projected impacts (whenever they might occur) as

2 Public service providers in Wales undertake 4-yearly local well-being assessments under the Well-being of Future Generations (Wales) Act 2015. They assess not only their citizens' state of well-being but also the effectiveness of public agencies' current policies and practices to promote well-being. Such well-being assessments include a consideration of resilience to climate change. See https://futuregenerations.wales/about-us/future-generations-act/ (accessed 22 June 2020).

opposed to particular dates. Any accompanying economic analysis would have to adopt a similar approach and this would raise issues around discount rates, which are normally structured around time into the future. Economic analysis is part of the iterative process of adaptation, repeated within climate risk screening, through the design and implementation of adaptation plans to the ongoing monitoring of effectiveness.

In this section, economic and socio-economic aspects of risk and adaptation evaluation have been introduced; these are especially useful to guide the planning and policy discussion of the adaptation strategies that will be needed to address risk at specific regional and local levels. Socio-economic approaches are required to assess, prioritise and implement adaptation goals and objectives (DCCAE, 2018c). Appraisal methods are presented that are used to evaluate adaptation plans in response to and proportionate to climate change risk. This research bridges the gap from vulnerability and risk assessments to the assessment of adaptation plans.

The information requirements for the analyses presented are significant. The clarity and accuracy of the analyses are tied to the level of detail provided. Similar to a tiered assessment approach, a phased approach to adaptation is considered the best approach, with different appraisal methods used at different planning stages (Bullock *et al*., 2015). The type and resolution of the analysis changes as climate, cost and threshold information becomes available and the quality of the data improves.

2.7 Mainstreaming

Mainstreaming involves the incorporation of climate change considerations (mitigation actions, vulnerability and risk assessments and adaptation actions) into all government activities and decision-making, such as infrastructure programmes and environmental assessments. Climate mainstreaming means that managers and budget holders who are not directly involved in climate action should also work to address and take ownership of climate change risk within their work. The NAF discusses mainstreaming in detail (DCCAE, 2018b). The World Resources Institute (Mogelgaard *et al*., 2018) has identified key factors that can help adaptation mainstreaming move from aspirational good intentions to implementation:

- strong policy frameworks;
- sustained and persistent leadership;
- co-ordination mechanisms across sectors and between government departments;
- information and tools;
- supportive financial processes.

Mainstreaming climate change provides an opportunity to make more efficient and effective use of financial and human resources. It can operate alongside developing specific adaptation and mitigation initiatives separately. Climate action would be integrated into all of the main spending areas. Mainstreaming requires co-ordination among multiple actors, e.g. buy-in from national departments responsible for finance and planning, with technical support from the DCCAE or the EPA. While the need for an integrated approach is generally accepted, how to go about mainstreaming climate change in an authentic manner is difficult (NESC, 2019). In April 2019, Ireland was one of more than 20 countries that joined the Coalition of Finance Ministers for Climate Action. The coalition recognises the crucial role that finance ministries have in promoting national climate action through fiscal policy and the use of public finance. Some tools/approaches used for mainstreaming are portfolio screening and budget tagging and tracking.

2.7.1 Budget tagging and tracking

Climate budget tagging is a tool for monitoring and tracking climate-related expenditures in the national budget system. A strong policy framework could set minimum targets for expenditure attributable to climate adaptation goals across budgets. This sends a strong message about the relevance and importance of climate change actions to planning officers, policy managers and budget holders, who are not climate change experts and may not see the role they can play in achieving national climate objectives. Tools and training in budget tagging would need to be provided to departments and relevant agencies. Tracking of climate-related expenditure can apply at the development planning stage and ensure that outcomes reflect policy by using tracking as a monitoring and evaluation indicator. Although it could provide a clear picture for government and citizens regarding investment in climate change, the system may prove too onerous or too subjective for practical application.

The Organisation for Economic Co-operation and Development (OECD, 2016) proposes that for tracking purposes the relationship between the activity and climate change adaptation is clearly communicated and made explicit. The Rio markers are policy markers used for monitoring of and statistical reporting on the financial flows associated with the Rio Convention themes, including climate change adaptation (climate risk mitigation and vulnerability reduction). When climate adaptation is not an objective, no finance is attributed to adaption; if climate adaptation is significant but not the predominant objective, a percentage of the project finance is tracked as being adaptation related; and when the primary objective is climate adaptation, 100% of the project finance is attributed as adaptation finance. The Rio markers provide a rough estimate of budget expenditure on climate adaptation actions and may not capture small climate-relevant components of large projects that are not primarily focused on climate change. The methodology used by the multilateral development banks' climate finance group captures small projects and components of large projects.

3 Thematic Tiered Risk Assessment

A CCRA is an informed process that leads to increased understanding and management of the risks of climate change to societal well-being and natural and cultural capital, as well as to infrastructure and other assets essential for economic security. In accordance with the requirements of Tonmoy *et al*. (2019), and for the purposes of identifying and assessing climate change risks for Ireland, a tiered approach to CCRA has been employed in this study.

A literature review was undertaken to identify the wide range of hazards and risks that Ireland faces and, through stakeholder consultation, priority climate hazards resulting in risks were identified (first-pass assessment). On the basis of the identified hazards, expert judgement was employed to identify and prioritise climate change risks (second-pass assessment) for further assessment and to provide case study examples (third-pass assessment) (Figure 3.1).

3.1 First-pass Assessment

To identify and prioritise the range of climate hazards, potential impacts and risks, a stakeholder workshop was held in 2017. Workshop participants represented both policymakers and technical experts at the national level and included representatives from government departments, national agencies and industry. The workshop had two interconnected areas of inquiry:

1. identifying priority climate hazards on the basis of projected future impact (accounting for magnitude and likelihood);
2. identifying key climate risks at the national scale.

As detailed in Table 3.1, in the short term, priority climate risks are associated with rising sea levels, increased frequency and intensity of flooding, increased frequency and intensity of wind storms, freezing conditions and overall changes in climate. In the medium to long term, risks associated with rising sea levels are expected to increase, particularly in the context of projected increases in the intensity of coastal storms. Risks associated with projected increases in temperature and low levels of precipitation, resulting in heatwaves and drought, are expected to increase in the long term, while risks associated with freezing conditions are expected to decrease.

3.2 Second-pass Assessment

As part of the second-pass assessment – the literature review and expert consultation workshop held in November 2018 – key risks were identified and assessed according to the policy and science context. To align with the NAF, these risks were categorised according to the following key themes:

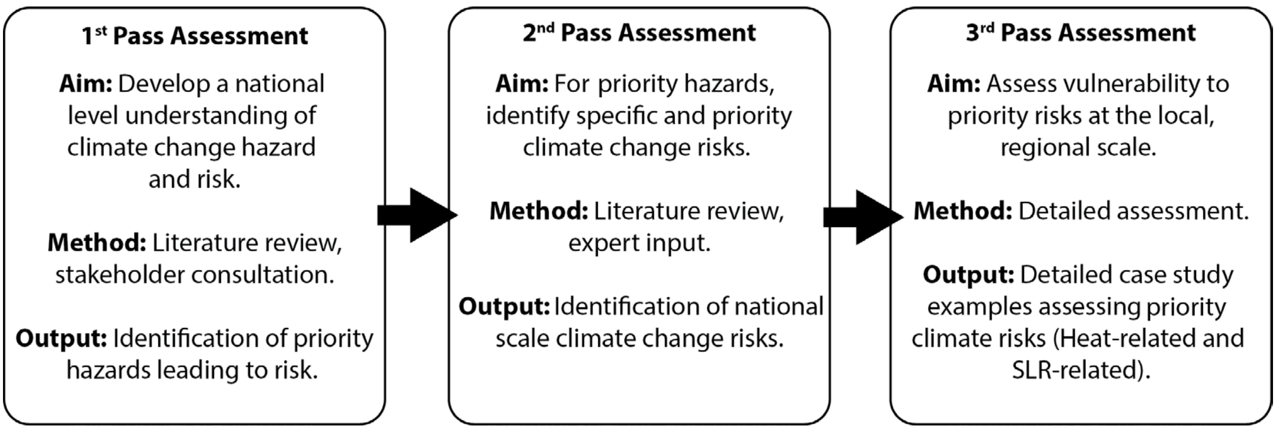

Figure 3.1. Assessment approach used to identify and assess climate change risks for Ireland, in accordance with the method of Tonmoy *et al.* (2019).

Table 3.1. Results of the hazard prioritisation workshop

Hazard	Short term (0–5 years)	Short to medium term (6–20 years)	Medium to long term (21–50 years)	Long term (>50 years)
Rising sea levels (coastal inundation and erosion)				
Increase in intensity of coastal storm events (coastal inundation and erosion)				
Increase in frequency of extreme precipitation (flooding)				
Increase in frequency and intensity of strong winds (storms)				
Increase in high temperatures and low levels of precipitation (heatwave and drought)				
Low-temperature events (freezing)				
Overall changing climate conditions				

The three colours provide a traffic light system of hazard prioritisation. Green indicates a relatively low level of prioritisation, orange indicates a medium level of prioritisation and red indicates a high level of prioritisation.

- natural and cultural capital;
- critical infrastructure;
- water resources and flood risk management;
- public health.

3.2.1 Natural and cultural capital

The natural and cultural capital theme covers a range of elements (both physical and biological): wildlife, rivers and streams, lakes and seas, urban green space and open countryside, built and archaeological heritage, forests, fisheries and farmland. The ecosystem services provided by the natural environment (e.g. clean air, water, food, fuel, medicines, recreation and tourism, protection from extreme weather) are the foundation of sustained economic growth and personal well-being. Ireland has a rich diversity of ecosystems and wildlife in its terrestrial, freshwater and marine environments, with over 31,000 species recorded terrestrially and in its surrounding seas (NBDC, 2010).

Globally, biodiversity is declining and remains threatened by human activities. Major causes of global biodiversity loss include overexploitation of wild species and conversion of land to agricultural use. In response to the global loss of biodiversity, the UN Convention on Biological Diversity (CBD) was established in 1992 (UN, 1992) and ratified by Ireland in 1996. The objectives of the CBD are "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources" (UN, 1992). The landmark Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 2019 global assessment report provided a stark overall key message: nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide (IPBES, 2019). The drivers of this change are many, with Figure 3.2 illustrating direct and indirect drivers and examples of decline.

Ireland's sixth national report to the UN CBD acknowledged that, in common with other countries, biodiversity in Ireland is impacted by habitat loss, changes in land use, pollution and climate change (DCHG, 2019a). Species and habitat decline are primarily linked to historical land use changes in Ireland. For example, the decline or loss of farmland bird species, such as the corncrake, yellowhammer and corn bunting, can be attributed to changes in agricultural practice such as a nationwide reduction in mixed farming with small-scale cereal growing, moving instead to specialisation in livestock production. The decline in bees, butterflies and other insects has largely resulted from the effect of monoculture and the drive to ever higher levels of productivity, characterised also by a loss or neglect of hedgerows, farmland

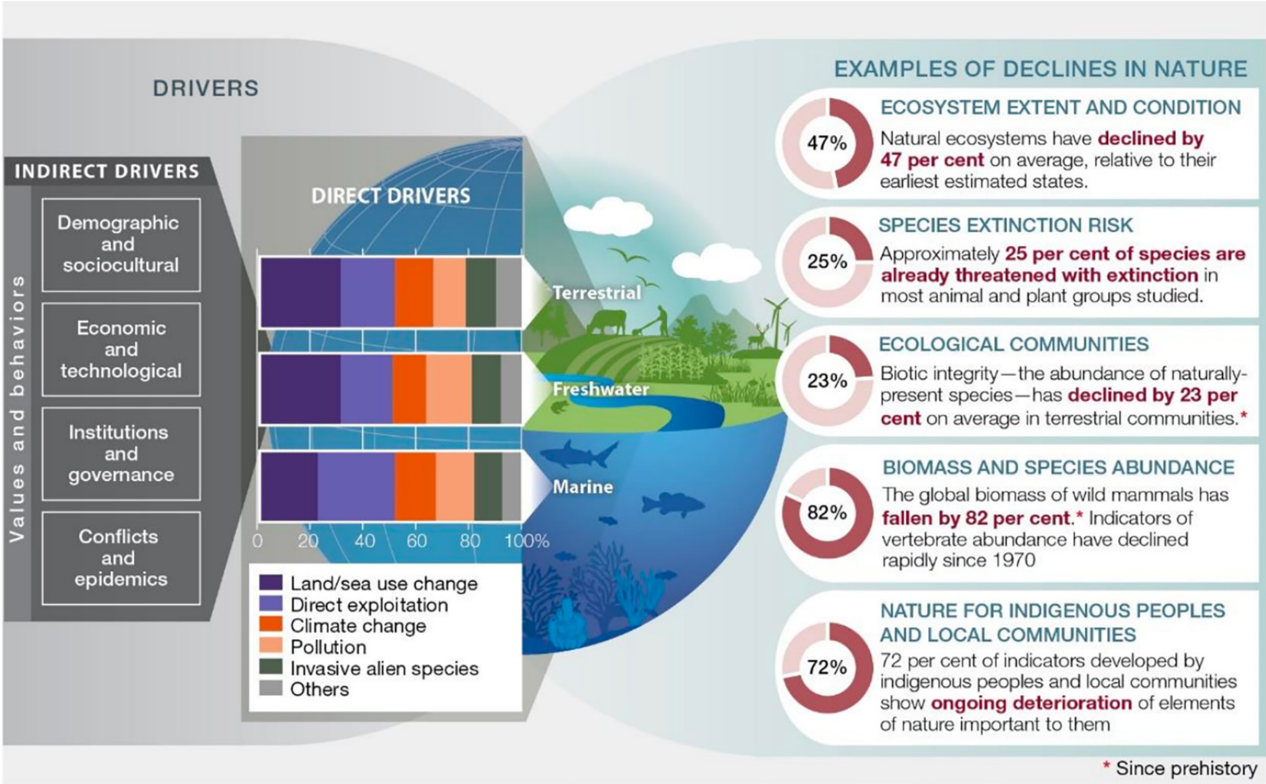

Figure 3.2. Examples of global declines in nature, emphasising declines in biodiversity, that have been and are being caused by direct and indirect drivers of change. Source: IPBES (2019).

edges and scrub (DCHG, 2019a). In addition to this historical legacy, climate change may be inducing changes in the distribution or migration of some flora and fauna, including cetaceans and fish species, and is a probable factor in the decline of charismatic species such as the puffin.

Policy context

The principal national legislation providing for the protection of wildlife in Ireland is the Wildlife Act, 1976 (ISB, 1976). This act provides for the designation of statutory nature reserves, refuges for fauna and wildfowl sanctuaries, as well as the protection of listed species of plants and animals. The Wildlife (Amendment) Act, 2000 (ISB, 2000a) strengthened the legislative basis for biodiversity conservation and gives statutory protection for the designation of national areas of high biodiversity: NHAs.

In addition to national policy, Ireland has made biodiversity commitments on both regional and international scales. Compliance with international agreements such as the Convention on International Trade in Endangered Species (CITES; https://cites.org/), the Bonn Convention on the Conservation of Migratory Species of Wild Animals (CMS, 2019) and the Global Strategy for Plant Conservation (GSPC; https://www.cbd.int/gspc/), as well as the CBD, remains an important mainstay of Ireland's biodiversity policies. The EU Habitats Directive (92/43/EEC) is the cornerstone of Europe's nature conservation policy (EC, 1992). It is built around two pillars: (1) the Natura 2000 network of protected sites (called SACs in the Habitats Directive, and SPAs in the EU Birds Directive – 2009/147/EC); and (2) systems for the protection of species outside these protected areas.

The two nature directives are transposed into Irish law by the European Communities Birds and Natural Habitats Regulations (ISB, 2011). Protection for biodiversity is also considered as part of other EU directives. The Marine Strategy Framework Directive (2008/56/EC) contains the explicit regulatory objective that "biodiversity is maintained by 2020" as the cornerstone for achieving Good Environmental Status (EU, 2008). The Water Framework Directive (2000/60/EC) (WFD) aims for the protection of all surface waters and groundwater, with the aim of reaching good status in all waters (EU, 2000), and is linked to a number of other nature-focused EU directives, including directives relating to the protection of biodiversity (the Birds and Habitats Directives). The Nitrates Directive (91/676/EEC), which aims to protect water from pollution by nitrates from agricultural sources, is the primary agricultural measure in place to support delivery of the WFD objectives (EU, 1991).

The EU Integrated Marine Policy (IMP) also promotes "blue growth" as a long-term strategy to support sustainable growth in the marine and maritime sectors as a whole (EC, 2019a). The IMP aims to provide a more coherent approach to maritime issues, with increased co-ordination between different policy areas. It focuses on issues that do not fall under a single sector-based policy and issues that require the co-ordination of different sectors and actors.

On the natural capital side, the Irish government has published the Biodiversity Climate Change Sectoral Adaptation Plan (DCHG, 2019b). On the built and archaeological cultural capital side, the Irish government has recently published a Climate Change Adaptation Sectoral Plan for Built and Archaeological Heritage (DCHG, 2019c). The Department of Agriculture, Food and Marine has also produced an Agriculture, Forestry and Seafood Climate Change Sectoral Adaptation Plan (DAFM, 2019). The production of all three of these plans was mandated under the NAF.

Science context

The IPCC's Fourth and Fifth Assessment Reports provide a wealth of evidence that species, at global, regional and national scales, are shifting their ranges in response to changes in regional climates and altering their phenology,[3] and that some species are facing extinction or have become extinct (Fischlin *et al*., 2007; IPCC, 2014). This evidence base included changes in species' altitudinal and geographical ranges and changes to habitats, population density, community structure, species genetics and evolutionary patterns, a reality that can impact both wild and cultivated species. Therefore, developing effective strategies to, where possible, offset the climate change threats to species' persistence is critical for maintaining species and genetic diversity at all scales, as well as economic well-being and food security.

One approach to monitoring potential changes to biodiversity includes mapping of land use and land cover. Land cover data enable the study and understanding of changes in environmental systems over time, as well as the identification of possible conflicts between socio-economic land use and ecological systems, biodiversity and natural landscapes. On a more local scale, the land cover data can show how man-made surfaces, agricultural lands and ecological communities are changing and interacting. In Ireland, land cover has been established through European efforts. The CORINE (Coordination of Information on the Environment) data series was established by the EU as a means of compiling geospatial environmental information in a standardised and comparable manner across the European continent (EEA, 1995; Lydon and Smith, 2014).

The CORINE Land Cover (CLC) dataset maps land cover based on two main properties: its natural bio-geographical properties (e.g. peatlands and natural grasslands) and its anthropogenic uses (e.g. pastures, arable land). These data are used widely by public bodies, researchers, scientists and private companies for a range of applications, including water management, air quality management, land planning, waste management, telecommunications and agriculture/forestry management. Moreover, it must be noted that the resolution of the CLC dataset has improved significantly over time. Its geometric accuracy (closeness of measurement to its true value) of ≤50 m in 1990 has been reduced to ≤10 m (using Sentinel-2 satellite outputs) in the 2018 iteration (Copernicus, 2019). In addition, a series of NHAs, SACs and SPAs have been established in Ireland, at least in part to conserve biodiversity and natural capital (DCHG, 2015).

Progress is being made in Ireland in mainstreaming biodiversity and bringing the ecosystem services concept into decision-making across sectors. There is a growing recognition of the wider benefits of considering biodiversity and ecosystem services, in particular in the agriculture, forestry, marine and tourism sectors (e.g. Harnessing Our Ocean Wealth, Food Wise 2025, Origin Green, Green Low-Carbon Agri-Environment Scheme).

3 Phenology is the study of periodic plant and animal life-cycle events and how these are influenced by seasonal and interannual variations in climate, as well as habitat factors (such as elevation).

Natural and cultural capital play a large role in Ireland's economy and well-being (DPER, 2018; DCHG, 2019b). The direct and indirect impacts of climate change on the natural environment are expected to be significant in the long term (2050 and beyond), potentially further exacerbating existing pressures on ecosystems and contributing to the further decline of some species, as well as impacting on water, food production and land and soil erosion (DAFM, 2017). In particular, the natural environment is vulnerable to cascading effects that can potentially result in non-linear ecosystem responses, resulting in loss of ecological function and with major implications for human well-being. As function is reduced or lost, the buffering that the natural environment provides against hazards such as flooding, erosion or pests is sharply reduced. Significant research has also been carried out by the European Environment Agency on climate change impacts on natural capital through the development of a series of indicators of the impact of climate change on European environments (EEA, 2016).

One key area for research, therefore, surrounds the capacity of the natural environment to continue to provide vital buffering against climate hazards, and understanding more about how this capacity could be further enhanced. This may mean that more transformational strategies to sustain natural and cultural assets may be necessary to be better prepared for future change. For example, climate-driven range shifts of native flora and fauna could impact on compliance with EU directives requiring maintenance of designated areas. As species change location because of the changing climate, there may be a need to shift designated areas to provide protected habitats for our native flora and fauna. The Department of Culture, Heritage and the Gaeltacht's 2019 Biodiversity Climate Change Sectoral Adaptation Plan elaborates on these issues in detail (DCHG, 2019b). With climate change, some species will end up outside their ecological "comfort zones", and that is where the second prong of the strategy comes in, namely, facilitating the movement of species to different, more suitable areas, and in all areas encouraging the establishment of new biological communities that are suited to the new climate. More attention should also be paid to maintaining the "supporting services" in each ecosystem (i.e. water cycle, carbon cycle, nutrient cycles, soil formation and retention), as these provide the foundation for provisioning, regulating and cultural services (DCHG, 2019b).

Risk assessment

Table 3.2 presents a (second-pass) risk assessment of the climate change-driven risks and opportunities for natural and cultural capital. The list was compiled by consulting existing draft climate change adaptation sectoral plans and workshop outputs from the project, as well as outputs from a Climate Ireland workshop. The inclusion of inputs from expert stakeholders in compiling the risk assessment captures the experience of practitioners on the ground; this complements the published literature with lived experiences of risk. The table considers climate hazards, impacts and consequences and can provide a useful tool in generating risk statements.

The hazards, impacts and consequences in Table 3.1 are not intended to be an exhaustive and complete list, but rather provide a useful way to link natural hazards to climate impacts and consequences in the natural and cultural capital sector at large. As documented in the stakeholder workshops, and reflected in the sectoral and local authority climate adaptation plans, the key hazards are related to increased precipitation, inland floods and coastal flooding, erosion and accretion (driven by SLR and an increased intensity of coastal storms). Impacts are felt across a wide range of natural and cultural capitals, including forestry, biodiversity, agriculture, seafood, built and archaeological heritage, and tourism. Noted impacts and consequences relate to the deterioration of and damage to built heritage, a significant loss of biodiversity, negative impacts on the supply of animal feed (fodder) and negative impacts on tourism because of road and infrastructure damage, for example. Opportunities for crop diversification and an increased shoulder season[4] for tourism are two noted potential positive impacts.

4 The shoulder season is a travel season between the peak season and the off-peak season, especially spring and autumn, when fares tend to be relatively low.

Table 3.2. Climate change-driven risks and opportunities for natural and cultural capital

Hazard	Impact	Consequence
Increased frequency of extreme precipitation	Waterlogging of agricultural land	Negative impact on animal health and reduction in grazing ability of farmland
		Decreased trafficability by machinery, difficult harvesting conditions and reduced harvesting windows
	Flooding of built and natural heritage sites	Access difficulties, impacting on tourism
		Damage to heritage and cultural assets, leading to increased costs associated with repair and maintenance
	Increased levels of surface nutrient run-off	Increased compliance difficulties with the EU Nitrates Directive, especially regarding slurry storage and land spreading
		Eutrophication and algal growth in rivers and water bodies
	Flooding of habitats and changes to the structure or geomorphology of river and coastal areas	Degradation of biodiversity and ecosystems – water bodies and wetlands
	Effluent ponding at wastewater treatment systems	Run-off, with subsequent impacts on water quality
Increase in frequency and intensity of strong winds	Erosion of soil and damage to vegetation and habitats	Increased habitat and biodiversity loss
	Damage to historical buildings and cultural assets	Repair costs, strengthening costs and potentially irreparable damage
	Increased frequency of sea surges	Damage to beach and dune ecosystems, as well as structures
Rising sea levels	Coastal erosion and inundation	Impact on coastal tourism businesses (e.g. Wild Atlantic Way)
		Damage to coastal habitats such as dune and machair systems
		Damage to coastal-based historical built heritage
Increase in frequency of high temperatures and low levels of precipitation	Poor pasture growth or an inability to utilise the pasture because of poor soil conditions	Reduced grazing quality, which can carry through to the grazing season and lead to the need for supplementary feed
	Extension of the growing season	Increased crop-growing opportunities
	Increase in aquatic plant growth in freshwater lakes	Limited access to lakes to conduct bird breeding surveys
		Impact on breeding birds' food sources and overall health
	Increased tourist numbers at heritage and cultural sites	Damage to natural and built heritage (e.g. damage to natural sand dune systems)
	Changes in soil moisture	Changes in wood quality and the need to change the tree species that are planted
	Increases in animal heat stress	Increased animal morbidity and mortality
	Reduced water table and reservoir levels	Increased demands on existing water supplies for agriculture and heightened competition for water resources
	Increase in drought conditions	Increase in forest fires
		Increase in fires in areas of natural beauty and associated disturbance/damage of flora and fauna
Low-temperature events	Increases in animal overwintering stress	Increase in animal morbidity and increased demand on limited fodder supplies
	Persistent snowfall and frozen ground	Increased mortality rates for wildfowl and deer
	Increased damage to older and historical buildings	Increased repair costs or complete loss of buildings
Overall changing climate conditions	Establishment and spread of vector-borne animal diseases	Increased animal treatment costs and animal fatalities
	Changing growing conditions	Opportunities for crop diversification
	Warmer average temperatures	Increased shoulder season for tourism
Increased intensity of storm events	Difficult on-the-ground conditions	Increased health and safety issues for farmers and livestock
	Fallen trees	Restricted access on roads and to natural sites and costs of removal and site repair
Increased intensity of coastal storm events	Coastal flooding and inundation	Erosion and damage to coastal habitats (machair and sand dune systems)

3.2.2 Critical infrastructure

Ireland depends on a reliable water supply and waste treatment systems, a dependable energy supply, a functioning transport network and an efficient communications network for both residential and commercial activities. The critical infrastructure theme covers all of these aspects, with the acknowledgement that the country's infrastructure accounts for more than half of its capital stock and accounts for the single largest area of national expenditure each year (IAE, 2009; Engineers Ireland, 2018). A two-pronged approach of maintenance and retrofitting of existing infrastructure that may be vulnerable to current climate conditions, as well as designing new infrastructure that is secure and flexible enough to cope with projected changes, is necessary to ensure continuity of service (EC, 2019b,c). The reality that the lifespan of some infrastructure assets can be between 50 and 100 years means that uncertainty associated with climate change projections is particularly important to recognise in planning and engineering cycles (EC, 2019b).

Policy context

One of the key pieces of national legislation on infrastructure in Ireland remains the Planning and Development Act, 2000 (ISB, 2000b). This act, and subsequent amendment (ISB, 2017), cover a large range of planning-related issues and consolidate different legislation in one place. Both documents set out the details of regional planning guidelines, development plans and local area plans, as well as special requirements for protected structures, conservation areas and areas of special planning control that govern where critical infrastructure can be sited.

In addition, Project Ireland 2040 outlines the role of the planning system in facilitating mitigation of, and adaptation to, climate change and ensuring that sustainable infrastructure networks build resilience to climate change (Government of Ireland, 2018). Project Ireland 2040 is informed by the National Planning Framework and the National Development Plan 2018–2027 (Government of Ireland, 2018). This combination emphasises the need for social outcomes and values to be evaluated alongside economic targets. Such planning must be supported by a significant commitment of investment resources, while also allowing for the flexibility to respond to future challenges. For example, by 2040 the population of Ireland is expected to grow by over 1 million to 5.7 million.

The National Development Plan also includes objectives in relation to the aim of transitioning to a low-carbon and climate-resilient society, including the allocation of €940 million for flood risk management projects, as well as an investment priority Climate Action Fund.

The Climate Action Fund will support initiatives from the public and private sector that will help Ireland reach its climate and energy targets (DCCAE, 2018d). It has the objective of funding initiatives that contribute to the achievement of Ireland's climate and energy targets in a cost-effective manner. Ten strategic outcomes have been identified for Ireland around the concept of development (Mogelgaard *et al*., 2018), building around the overarching themes of well-being, equality and opportunity (Government of Ireland, 2018). All of these need to take account of changing climate and weather patterns at multiple scales:

1. compact growth;
2. enhanced regional accessibility;
3. strengthened rural economies and communities;
4. sustainable mobility;
5. a strong economy supported by enterprise, innovation and skills;
6. high-quality international connectivity;
7. enhanced amenities and heritage;
8. transition to a low-carbon and climate-resilient society;
9. sustainable management of water and other environmental resources;
10. access to quality childcare, education and health services.

Critical infrastructure concerns are captured in a number of the sectoral adaptation plans, including those related to transport infrastructure, electricity and gas networks, and communications networks (DTTAS, 2017; DCCAE, 2018a).

Science context

The IPCC's Fourth and Fifth Assessment Reports recognise that the shift from rural to more urban societies is a global trend with significant consequences for GHG emissions and climate change mitigation efforts (IPCC, 2014). Estimates from 2016 for urban energy-related CO_2 emissions range from 71% to 87% (central estimate 76%) of all CO_2 emissions from global energy use (IEA, 2019). The 2016 census figures show that, in Ireland as a whole, just over a third (37%) of the population lives in rural areas. Therefore, developing effective strategies to, where possible, offset the climate change threats from infrastructure and population concentration is critical for long-term economic and social goals, e.g. the commitment in the government energy White Paper, *Ireland's Transition to a Low Carbon Energy Future*, to decarbonise Ireland's energy system by "at least 80%" by 2050 (DCCAE, 2015b). It must also be noted that, while intensification of urban areas may increase GHG emissions, this is not inevitable; there are equally opportunities to reduce emissions, for example by reducing the need to travel and adopting neighbourhood energy schemes.

Globally, the increased frequency of flooding from all sources has been highlighted as one of the most significant climate change risks to infrastructure (Dawson *et al.*, 2018; EC, 2019b). Assets and networks across all infrastructure sectors are already exposed to multiple sources of flooding, and the number of assets exposed will increase under projected changes to precipitation patterns and sea levels (EC, 2019b,c). Coastal infrastructure is particularly vulnerable to storm surges and changes in storm frequency, as well as higher rates of coastal erosion, in many areas of Ireland (Devoy, 2008; Flood and Sweeney, 2012). Systems and buildings near rivers will also be increasingly vulnerable to higher flows and subsequent erosion, and surface water flooding will become a growing issue because of an increase in heavy precipitation events and the reduced permeability of surfaces (under business-as-usual urban planning) in expanding urban areas.

In addition, projected changes in temperature will exacerbate existing pressures on the rail, road, water and energy sectors (IAE, 2009; Engineers Ireland, 2018). High temperatures create a risk of buckling on the rail network and cause electricity cables to sag and road tarmac to soften and rut. Components such as signalling equipment can overheat and fail. Changes in rainfall, coupled with population growth, are projected to lead to supply/demand deficits in water and sewerage capacity. Changes in wind speeds during storms could have significant implications for overhead power lines, data network cabling and the rail network, as well as for the capacity of offshore renewables to contribute to Ireland's low-carbon sustainable future. In addition, the cascade of higher rates of vegetation growth (see section 3.2.1) is expected to result in more tree-related failures for electricity and transport networks to deal with.

Datasets on housing density, transport networks, electricity and gas networks, coastal defences, water and sewerage networks and communications infrastructure all help to determine key areas of criticality in Ireland. These tend, however, to be controlled by different sectors or private enterprise, which makes interconnected planning challenging. This is a critical issue as failures in one infrastructure sector can quickly cascade into others. For example, failure of the electricity supply can lead to the failure of pumping systems (leading to flooding) and communication systems (leading, for example, to failure of financial transaction services such as credit card payments). The issue of overall co-ordination and control is therefore absolutely crucial. An important strength of risk assessment is the key advice it can provide on how to set about adopting a co-ordinated "systems" approach, as opposed to a "sector by sector" approach, to climate risk management. The EPA research project "Critical Infrastructure Vulnerability to Climate Change (CIViC)" provides a detailed risk assessment across Ireland's critical infrastructure network (taking a second-pass risk assessment approach) before applying a third-pass risk assessment to assess climate change-driven risk in Ireland's power distribution network, using probabilistic analysis to examine the vulnerability of power lines (electricity poles) (Hawchar *et al.*, 2020).

Risk assessment

Table 3.3 presents a (second-pass) risk assessment of the climate change-driven risks and opportunities for critical infrastructure. The list was compiled by consulting existing draft climate change adaptation sectoral plans and workshop outputs from the project, as well as outputs from a Climate Ireland workshop.

Table 3.3. Climate change-driven risks and opportunities for critical infrastructure

Hazard	Impact on infrastructure	Consequence
Increased frequency of extreme precipitation	Increases in pluvial (surface) flooding leading to impacts on bus services and light rail	Increase in delays, overcrowding of services, disruption of services
	Increased risk of slope erosion and landslides	Damage to property and infrastructure and possible loss of life
	Increased storm water flooding leading to impacts on ports and airports	Challenges to storm water management in airports and port radar ability compromised during heavy precipitation events
	Flooding of vulnerable housing	Increased repair and temporary accommodation costs
	Increased storm water flooding leading to impacts on ports	Impact on dredging requirements – positive or negative depending on location
	Undercapacity in surface water drainage systems in urban areas	Flooding of streets, properties and businesses
	Increased flooding (pluvial and fluvial)	Increased strain on services to carry out clean-up and recovery activities
	Increased storm water flooding	Damage to pavements, road washout, road submersion, underpass flooding, overstrained drainage systems, risk of landslides, instability of embankments
Increase in frequency and intensity of strong winds	Impacts on heavy rail operation	Interruption to operation of automatic level crossing barriers, damage to signalling and power equipment from falling trees, damage and/or blockage of tracks from fallen debris and rock falls
	Damage to power and communication infrastructure	Increasing service disruption across power and communication networks
	Impact on operation of light rail	Danger from overhead contact wires and speed restrictions because of high winds
	Increase in number of (especially mature) fallen trees	Closure of roads, travel disruption, damage to property and possible loss of life
	Loss of available workdays on construction sites	Delays in and associated increased costs for construction projects
	Disruption of air travel	Negative impact on tourism and the economy at large
	Increases in coastal sea surges	Damage to critical infrastructure
Rising sea levels and increased frequency of storm surges	Increased coastal flooding	Damage to coastal road surfaces (especially western coastal routes)
	Erosion of soft areas of coastline	Damage to coastal buildings and infrastructure
	Increased surges in ports	Damage to port infrastructure and damage to vessels in ports, impact on safety of passengers while in transit/embarking/disembarking
	Flooding and erosion of coastal roads	Damage to roads, transport disruption and associated increased maintenance and repair costs
	Increased coastal erosion	Increased costs associated with damage, possible need to relocate underground power cables and gas distribution pipelines
	Damage to coastal defence structures and associated infrastructure	Increased costs of repair and maintenance
Increase in frequency of high temperatures and low levels of precipitation in summer months	Overheating in building/housing stock	Increased cooling costs, heat damage and material fatigue
	Heavy rail and road infrastructure damage	Increase in rail buckling/misalignment of tracks and melting of tarmac on roads
	Damage to buildings and infrastructure from heat damage and subsidence	Increased costs of maintenance and repair
	Damage to power infrastructure (overhead wires, underground cables, transformers and substation sites)	Increased maintenance and repair costs
	Deterioration of surfaces (melting) and foundations (subsidence) of regional and local roads	Failure and/or increased maintenance costs
	Better conditions for construction	Reduced construction costs and improved programmes

Table 3.3. Continued

Hazard	Impact on infrastructure	Consequence
Low-temperature events	Increase in levels of ice and snow	Delay in some construction activity (concrete pouring and bitumen application) resulting in increased costs
		Transport disruption impacting on road network access and leading to increased costs for winter maintenance
	Increase in damaged and cracked road surfaces	Additional repair costs and costs associated with road strengthening
Increase in storm events	Damage to power infrastructure (overhead lines, underground cables, transformers, network access) and gas infrastructure (transmission pipelines, compressor stations, pressure reduction installations)	Increased maintenance and repair costs, delay in repairs because of limited access under flooding conditions
	Increase in pluvial (surface), fluvial (river) and coastal flooding	Damage to rail bridges, tracks and rail depots
	Increase in fluvial (river) flooding	Damage to runway drainage systems and flood defence embankments

Critical infrastructure located along Irish coastlines is particularly exposed to climate change hazards. SLR will exacerbate these associated risks. An important point to note with all critical infrastructure is the interdependencies between systems, for example sewage treatment facilities are dependent on reliable power sources and, in many cases, transport infrastructure, for the transport of goods and services. Moreover, damage to critical infrastructure leads directly to immediate impacts on human populations in the form of reduced welfare and health impacts. For example, power outages after a significant storm event can be compounded by disruptions to transport, because of the closure of roads, resulting in physical and mental health impacts on affected communities.

3.2.3 Water resources and flood risk management

Flooding, as defined in the EU Floods Directive (2007/60/EC), is a temporary covering by water of land that is normally dry; it is a natural process that can happen at any time in a wide variety of locations. Flood hazard is the potential threat posed by flooding to people, property, the environment and our cultural heritage (OPW, 2015). The degree of hazard is dependent on a variety of factors that can vary from location to location and from one flood event to another. These factors include the extent and depth of the flooding, the rate of flow or velocity over the flood plains, the rate of onset and the duration of the flood.

Flooding can occur from a range of sources, including:

- coastal flooding, from the sea and estuaries;
- fluvial flooding, from rivers, lakes and streams;
- pluvial flooding, where intense rainfall leads to overland flow and ponding;
- groundwater flooding, particularly from turloughs after prolonged wet periods;
- flooding from infrastructure, such as from reservoir breaches or blocked or surcharged piped networks.

Flood risk is the damage that may be expected to occur at a given location as a consequence of flooding. It is a combination of the likelihood, or probability, of flood occurrence, the degree of flooding and the impacts or damage that the flooding may cause. Flooding can cause damage, loss or hardship in a number of ways, including:

- impacts on people and society (including physical injury, illness, stress and loss of life);
- damage to property (such as homes and businesses);
- damage to and loss of critical infrastructure (such as water supply or roads);
- impacts on the environment (such as damage to or pollution of habitats);
- damage to cultural heritage (such as monuments and historical buildings).

In addition to flood risk, a changing climate also increases the prevalence of low precipitation events, especially in summer months (Dwyer, 2012). This can result in drought conditions with impacts on water quality and supply and other critical infrastructure needs, such as sewage treatment facilities. Futhermore, reduced river flow can result in a reduced capacity of rivers and streams to absorb discharges from some wastewater treatment plants.

Policy context

The WFD was adopted in 2000 as a single piece of legislation covering rivers, lakes, groundwater and transitional (estuarine) and coastal waters, including heavily modified and artificial water bodies (EU, 2000). Its objectives are to prevent the further deterioration of, and to protect, enhance and restore the status of, all bodies of water, with the aim of achieving at least good status by 2015.

The Water Policy Regulations [Statutory Instrument (S.I.) No. 722 of 2003; ISB, 2003], Surface Waters Regulations (S.I. No. 272 of 2009; ISB, 2009) and Groundwater Regulations (S.I. No. 9 of 2010; ISB, 2010) govern the shape of the WFD characterisation, monitoring and status assessment programmes in terms of assigning responsibilities for the monitoring of different water categories, determining the quality elements and undertaking the characterisation and classification assessments.

The Surface Waters Regulations contain a wide-ranging set of environmental standards for Irish surface waters. The Groundwater Regulations establish environmental objectives to be achieved in groundwater bodies and include groundwater quality standards and threshold values for the classification of groundwater and the protection of groundwater against pollution and deterioration in groundwater quality. Ireland's National Water Resources Plan (NWRP) aims to identify how to provide a sustainable, secure and reliable water supply, balancing the supply and demand for drinking water, over the short, medium and long term, with safeguarding of the environment (Irish Water, 2019). The plan is currently under public consultation and is due to be published before the end of 2020. The NWRP consultation documents specifically refer to the need to manage our water supply to cope with the impact of extreme weather events, citing Storm Emma in March 2018 and the drought events of the summer of 2018 (Irish Water, 2019).

A sectoral climate change adaptation plan on water quality and water services infrastructure was published by the Department of Housing, Planning and Local Government in 2019 (DHPLG, 2019), and a flood risk management climate change adaptation plan was produced by the Office of Public Works (OPW, 2015).

The WFD requires Ireland to have a system in place for the registration and control of the abstraction of water. A commitment to introduce legislation in this area was included in the River Basin Management Plan 2018–2021, which was published in April 2018 (DHPLG, 2018). The only legislation at present that deals with the abstraction of water is the Water Supplies Act, 1942 (ISB, 1942), which is focused on the abstraction of water for public supply, and there are currently no powers to regulate large-scale private abstractions of water that might have negative impacts on the water environment. The EU (Water Policy) (Abstractions Registration) Regulations 2018 (S.I. No. 261 of 2018; ISB, 2018), made under the European Communities Act 1972 (ISB, 1972), have established a register of abstractions to be managed by the EPA, with effect from 16 July 2018. All current abstractors of 25 m^3 or more per day are required to register via an online portal (http://www.epa.ie/licensing/watwaste/watabs/) and the EPA has been liaising since 16 July 2018 with Irish Water and the National Federation of Group Water Schemes, which together account for the volumetric bulk of such abstractions, regarding the registration of their abstractions. The EPA has published a Quick Abstraction Volume Estimator on its website to assist abstractors in deciding if they need to register a particular abstraction.[5]

5 Registration will enable the EPA to build up a nationwide picture of the extent and size of current abstractions in order to better manage abstractions in areas of high risk in future. All existing abstractors will be allowed to continue abstracting water in the first instance. When a clear national picture of abstraction pressures has been finalised, the EPA will be in a better position when a registration or a licence is due for renewal to assess particular water pressures and attach conditions or refuse registration or licensing if necessary. It is intended to charge an administrative fee for licence applications similar to that required at present for IPPC waste licences and waste licences issued by the EPA in order to make the regulatory regime self-funding.

Science context

Climate change is likely to have a considerable impact on flood risk in Ireland. The OPW notes that SLR increases the risk to coastal communities and assets and threatens coastal squeeze of intertidal habitats where hard defences exist (OPW, 2015). With projections that the number of heavy rainfall days per year may increase, this could lead to an increase in both fluvial and pluvial (urban storm water) flood risk, although there is considerable uncertainty associated with projections of short duration, intense rainfall changes due to climate model scale and temporal and spatial downscaling issues (OPW, 2015). Furthermore, the projected wetter winters, particularly in the west of Ireland, could give rise to increased groundwater flood risk associated with turloughs. These potential impacts could have serious consequences for Ireland, where all of the main cities are located on the coast and many of the main towns are located on large rivers.

As the lead government agency with a remit to minimise the impacts of flooding through sustainable planning, the OPW has considerable capacity and expertise in Irish flood risk management. It carries out flood and erosion mapping and has a dedicated website (www.floodmaps.ie) containing information on recorded flood events in Ireland. Its map viewer presents information by location and allows the user to add additional data layers on drainage districts and drainage schemes (OPW, 2015). It also provides water data from 380 surface water gauging stations at river, tidal and lake locations nationwide (www.waterlevel.ie). The majority of the stations provide real-time data. In addition, the OPW produces river flow data. The EPA provides assistance in collecting data from local authority gauges and in the quality assurance, archiving and dissemination of these data and also maintains the Register of Hydrometric Stations in Ireland. The OPW's Climate Change Sectoral Adaptation Plan 2015–2019 focuses on inland flood risk management (OPW, 2015). The plan reviews the existing science and outlines the potential increase in flood hazard and flood risk from climate change, drawing on work carried out under the national Catchment Flood Risk Assessment and Management (CFRAM) programme, including information for other sectors.

The OPW has also carried out considerable work in the area of coastal flood management. Its 2010 plan presents a strategic assessment of coastal flooding and erosion (OPW, 2010). The prediction of extreme water levels and the assessment of both coastal flooding and erosion hazards are critical in the development of any coastal protection strategy. This information is generated from the analysis of long-term historical tidal records, mapping and/or ortho-photography. However, these data are not available at a national level in Ireland. Alternative methodologies involve analytical and numerical modelling techniques (OPW, 2010). The Irish Coastal Protection Strategy Study website provides a wide range of technical reports and coastal flood maps for Irish coastal areas (OPW, 2010).

Significant research has also been carried out to gain an understanding of water resource management in an Irish context. In particular, Murphy and Charlton (2008) have examined the impact of climate change on water resources, Fealy and Murphy (2009) have examined the likely physical impacts of future climate change on inland waterways and the coastal environment in Ireland, Hall and Murphy (2013) have carried out a vulnerability assessment of surface water resources and Hall *et al*. (2012) have focused on robust adaptation options for mitigating climate change in the water sector in Ireland. This work has provided a foundation to inform the Irish NWRP. Furthermore, Irish Water is also carrying out its own in-house, as well as commissioned, research studies, under a number of projects and plans, on how best to manage our water resources (Irish Water, 2019).

Risk assessment

Table 3.4 presents a (second-pass) risk assessment of the climate change-driven risks and opportunities for water resources and flood risk management. The list was compiled through consulting existing draft climate change adaptation sectoral plans and workshop outputs from this project, as well as outputs from a Climate Ireland workshop.

Water resource and flood risk management again demonstrate the interconnectedness of sectors and the limitations, although functional and often practical, of silos. These two sectors interact closely, with strong interdependencies existing between them. Key hazards are related to changes in precipitation, with reduced precipitation leading to drought and increased precipitation driving flood conditions. Differentiating

Table 3.4. Climate change-driven risks and opportunities for water resources and flood risk management

Hazard	Impact	Consequence
Increased frequency of extreme precipitation	Increased (fluvial and pluvial) flooding	Water treatment plant disruption and contamination of the water supply
		Increased groundwater and drainage surcharge, resulting in damage to buildings, infrastructure and loss of life
		Increased flooding of vulnerable areas and increased pressure on emergency services
		Increased run-off and discharge into rivers and waterways, resulting in increased sediment and nutrient loading
		Ineffectiveness of surface water collection drainage networks, resulting in flooding of roads and property
Increase in frequency and intensity of strong winds	Wind-related damages	Power disruptions at wastewater treatment and water treatment plants, resulting in asset damage and service disruptions
	Increased sea surges and coastal inundation	Increased coastal erosion, resulting in loss of coastal land (including increased frequency of landslides) and damage to coastal property and infrastructure
	Increased storm impacts	Damage to wastewater and water treatment plants, resulting in disruption to the water supply
Rising sea levels and increased frequency of sea surges	Increased coastal inundation	Temporary submersion of low-lying coastal sites, leading to potential damage to domestic wastewater treatment systems and pollution of water
		Coastal water treatment plant disruption and impacts on the water supply
Increase in frequency of high temperatures and low precipitation	Reduced (pluvial and fluvial) flooding	Opportunities for construction
	Reduced river and stream flow	Reduced capacity of rivers and streams to absorb discharges from some wastewater treatment plants
	Increased drought conditions	Reduced flushing of sewer networks, leading to a build-up of grease and blockages in some sewer systems
		Decrease in the water supply and increase in water demand leading to supply restrictions on both public and private water networks, resulting in impacts on businesses, services and communities
		Reduction in sources of water (especially groundwater), resulting in reduced water quality and associated strain on water treatment facilities
	Increased temperatures in water bodies	Increased algal bloom growth and reduction in water quality and river navigability
	Reduced river and stream flow and low recharge of groundwater	Reductions in water quality and increased loss of fish
Low-temperature events	Changes in water body temperature	Impacts on aquatic plants and animals (living in or requiring access to water bodies) of temperature conditions deviating significantly from the norm
	Increase in snow, ice and freezing conditions	Frozen or burst pipes, resulting in increased pipe repair and road repair work
		Changes in water and wastewater treatment capability, resulting in reduced capacity

between fast- and slow-onset events is important when managing the water supply and implementing effective flood risk management. For example, gradual increases or decreases in precipitation levels can impact on the water flow in river catchments and reduce or increase the water supply and increase or decrease flood risk. High-intensity precipitation events (associated with storms) pose a different set of risks when it comes to flood risk management and the resilience of the water supply, testing the flood defence capacity and demanding rapid decision-making capabilities and the deployment of post-event support services to respond to property flooding and reinstate a safe drinking water supply.

3.2.4 Public health and well-being

Some populations are especially vulnerable to climate-related health risks because of particular sensitivities, high likelihoods of exposure, low adaptive capacity or combinations of these factors (IPCC, 2014). Communities of colour (including indigenous communities, as well as specific racial and ethnic groups), those on low incomes, immigrants and those with limited English proficiency are disproportionately vulnerable for a wide variety of reasons, such as their higher risk of exposure, socio-economic and educational factors that affect their adaptive capacity and a higher prevalence of medical conditions that affect their sensitivity (Bell and Greenberg, 2018).

Children are vulnerable to many health risks because of biological sensitivities and having more opportunities for exposure (such as playing outdoors). Pregnant women are vulnerable to heatwaves and other extreme events, for example flooding. Older adults are vulnerable to many of the impacts of climate change. They may have greater sensitivity to heat and contaminants, a higher prevalence of disabilities or pre-existing medical conditions or limited financial resources that make it difficult to adapt to impacts (Bell and Greenberg, 2018).

Occupational groups, such as outdoor workers, paramedics, firefighters and transport workers, as well as workers in hot indoor work environments, will be especially vulnerable to extreme heat and exposure to vector-borne diseases (IPCC, 2014). People with disabilities can be very vulnerable during extreme weather events unless communities ensure that their emergency response plans specifically accommodate them (IPCC, 2014; Bell and Greenberg, 2018). People with chronic medical conditions are typically vulnerable to extreme heat, especially if they are taking medications that make it difficult to regulate their body temperature. Power outages can be particularly threatening for people who are reliant on certain medical equipment.

Policy context

The 2013 EU Strategy on Adaptation to Climate Change identifies human health as a priority area (EC, 2013). The strategy suggests that as climate change impacts are expected to widen social differences across the EU special attention needs to be given to social groups that are most exposed and already disadvantaged. In 2018, the European regional office of the World Health Organization released a report outlining public health and climate change adaptation policies in the EU (WHO, 2018). The report presented a number of recommendations for developing public health adaptation actions. The technical, structural, managerial and operational improvements identified are captured in the following seven recommendations:

1. The health sector is responsible for protecting health from climate risks, but the ultimate responsibility is included in other sectoral policies too; therefore, the health sector cannot accomplish this task alone and needs to engage in intersectoral governance and the development of sectoral policies by providing public health arguments and advice.
2. A comprehensive approach should be adopted to integrate climate change-related risks into health systems.
3. The capacity of the health workforce should be developed to address climate change-related health risks.
4. Risk assessment, surveillance and research in relation to emerging climate change-related health risks should be established and the results incorporated into wider climate change policy planning processes.
5. The management of environmental determinants of health, climate-informed health programming and emergency preparedness needs to be strengthened.
6. Finance for health resilience to climate change should be scaled up.
7. Climate adaptation should be embedded in the EU budget, and countries, regions and cities should be further supported and encouraged to develop plans to build resilience and adapt to climate change, taking population health into account.

In conclusion, the WHO report found that stronger links between adaptation and public health are needed. Specifically, it suggested that improvements to cross-sectoral co-operation on risk assessment are needed to increase the awareness and capacity of the health sector to address current and emerging climate-related health risks. This could be facilitated through the development and dissemination of best practices and new knowledge on climate-related health risks through relevant EU-funded programmes (WHO, 2018).

Irish policy on health and climate change is more nascent. In 2010, the Institute of Public Health in Ireland issued a Platform for Action, which presented a number of policy actions linked to climate and health (IPH, 2010). Building on the recommendations from the IPCC, which call for health impact assessment of all policies addressing climate change, emphasising particularly the impact on health equity, was one of its key recommendations. The Health Service Executive (HSE) has also produced a set of potential impacts on health and Irish health services linked to a changing climate (HSE, 2019). The 2019 sectoral adaptation plan on health begins the process of bridging this important policy gap (DCCAE, 2020).

Science context

The impacts of climate change on human health and well-being in Europe are linked with changes in average temperatures, extreme temperature events, flooding, air pollution, and vector-borne and water- and food-borne diseases (IPCC, 2014, 2018; EEA, 2016). In many cases these impacts are set to increase and intensify in the future; for example, increases in extreme flooding could increase the risk of campylobacteriosis and cryptosporidiosis (EEA, 2012b).

Climate change in Ireland is also associated with impacts on human health and well-being. There are likely to be increases in heatwave-related health impacts, increases in food-borne diseases and increases in flood-related health impacts, as well as an increase in the burden of water-borne diseases and an increase in respiratory disease frequency, because of changes in the temporal and spatial distributions of pollen and pollutants (Cullen, 2008; Pascal *et al*., 2013).

A study by Eng and Mercer (1998) found that Ireland has a strong seasonal pattern of mortality, with a significantly higher winter mortality rate than summer mortality rate. In fact, the excess winter mortality in Ireland is one of the highest in the developed world (Healy, 2003); therefore, heat may not be immediately considered as a climate change-related risk to health. However, hot summers have been associated with increased mortality in Ireland (Pascal *et al*., 2013). Heat stress and increased mortality in vulnerable groups is considered a potential climate change impact in Ireland (Sweeney *et al*., 2008). Heatwaves are associated with increased energy use for cooling, an increased demand for water (Dwyer, 2012), decreased energy efficiency and decreased economic productivity (Dell *et al*., 2012).

Cities frequently experience higher mean average air temperatures than surrounding rural areas, a phenomenon referred to as the urban heat island (UHI) effect. The UHI effect means that urban areas are more likely to experience heatwave-type weather than the surrounding rural areas. There is no universal definition of a heatwave beyond a prolonged period of abnormally hot weather that may be accompanied by high humidity. Extreme hot weather looks different depending on the norm for the country or region.

Risk assessment

Table 3.5 presents a (second-pass) risk assessment of the climate change-driven risks and opportunities for public health. The list was compiled by consulting existing draft climate change adaptation sectoral plans and workshop outputs from this project, as well as outputs from a Climate Ireland workshop.

Public health sits at the nexus between the three other themes of natural and cultural capital, critical infrastructure, and water resources and flood risk management. Human health and well-being acts as an important bellwether to assess risk management and adaptation success, as the three aforementioned themes, and the sectors represented underneath them, impact on human health and well-being. The impacts of natural hazards and their associated consequences can result in increases or decreases in human physical and mental health and well-being, and as such they provide a measure of success in relation to risk mitigation and impactful adaptation actions to build adaptive capacity. Therefore, it is important to stress that successful management of climate risks has the potential to increase socio-economic resilience.

Table 3.5. Climate change-driven risks and opportunities for public health and well-being

Hazard	Impact	Consequence
Increased frequency of extreme precipitation	Increased (fluvial and pluvial) flooding	Increase in occurrence of vector- and food-borne diseases
		Closure or disruption of businesses, resulting in loss of business confidence and future investments and community impacts
		Ineffectiveness of surface water collection drainage networks, resulting in discharge of emergency overflows of combined sewers to water bodies, leading to increases in occurrences of water-borne parasites such as cryptosporidium, with population health implications
		Flooding threat to businesses and communities
		Reduced ability of wastewater treatment plants to operate, resulting in partially treated effluent being discharged to water bodies, with subsequent impacts on water quality and community health
		Disruptions to essential community services, e.g. refuse collections), leading to potential health implications for communities
		Support needed for HSE ambulance deployment to evacuate people from their homes and provide assistance and supplies
	Increased volumes of water on road surfaces	Increased demand on emergency response resources and impacts on the effectiveness of the services provided
Increase in frequency and intensity of strong winds	Increased storm impacts	Difficult driving conditions and increase in road accidents, resulting in additional pressures on emergency services
		Disruption of community, cultural and sporting events, resulting in loss of income and/or reputational damage
		Increased number of emergency service call-outs, resulting in a demand on resources and health and safety risks to staff attending emergencies
	Increase in unsafe driving conditions	Increase in flying debris, endangering property, infrastructure and lives
Rising sea levels and increased frequency of sea surges	Increased coastal erosion and inundation	Increase in office closures and loss of essential services to the community at a time when demand for these services is acute because of severe weather impacts
		General increased level of public health and safety impacts
Increase in frequency of high temperature and low precipitation	Increase in sunshine hours in spring and autumn periods	Additional emergency response call-outs and associated health and safety concerns for responders
	Deterioration of parks/recreational areas	Longer tourist season and associated positive impacts on businesses and local communities
	Increased drought conditions	Increased maintenance requirements for local authorities
	Increase in sunshine hours	Increased risk of fires (properties, forests, etc.) and an increased demand for fire service resources
		Increased levels of human heat stress at community and sporting events, resulting in heat-related health impacts
		Increase in demands on the tourism and hospitality sectors, leading to a greater demand on services (e.g. beaches) and the need for additional staff/resources (e.g. lifeguards)
		Increased opportunities for outdoor events and activities and an increase in demand for suitable facilities and supports
	Increased public discomfort	Greater demand for council staff leave, scheduling difficulties and potential reductions in service delivery
	Uncomfortably hot office working environments	Increased need for the provision of areas of reprieve by authorities
	Increased cooling requirements for current and planned building stock	Reduced work output and an increase in energy use associated with fans and air conditioning
	Health and safety concerns for people working outdoors	Increased energy consumption

Table 3.5. Continued

Hazard	Impact	Consequence
Low-temperature events	Increase in ice and snow	Increased transport disruption, cancellation of community and sporting events and subsequent negative impacts on community well-being
		Additional calls on emergency services and electricity supply repair works, resulting in additional costs and demands on limited services, and associated impacts on public health and safety
		Increased transport disruption, resulting in more road accidents

3.2.5 Summary of assessment themes

Using a second-pass tiered assessment methodology, the risk assessments detailed in the previous sections provide a valuable screening of the range of potential impacts and consequences associated with climate change and extreme weather events. They provide the groundwork for carrying out specific actions and highlight gaps where further data, analysis and research are needed. The risk tables are not intended to capture every conceivable risk to the systems under consideration; rather, they act as illustrative guidance on the creation of second-pass risk assessments.

A striking feature in examining the four themes in turn is the interdependencies and multiple risks occurring across them all. The health sector, in particular, raises interesting issues on the topic of mainstreaming climate risk. For example, the implementation of green urban design (under critical infrastructure) will have significant health co-benefits for urban-dwelling populations. Another key point to note is the different degrees of work already carried out on risk assessment across the themes. For example, considerable work has been carried out in the area of flood risk management in Ireland to date compared with health, for which research and policy linked to climate risk management and associated climate change adaptation needs are less mature.

The next chapter builds on this initial assessment by identifying appropriate responses to mitigate climate risks, adaptation options that can be put in place, and issues around mainstreaming adaptation action and risk management into everyday activities. Applications of a more detailed risk assessment process (second-pass into third-pass risk screening) are also provided to illustrate the iterative nature of carrying out a CCRA.

4 Third-pass Assessment (Case Study Applications)

In previous chapters a second-pass risk assessment was provided (Chapter 3) and adaptation evaluation techniques were introduced (Chapter 2). Overall, there is a framework rather than an exact formula for risk assessment and adaptation analysis. Therefore, case studies provide valuable lessons in the application of the framework. In this chapter, examples of third-pass risk assessments are provided and linked with appropriate adaptation responses. Two examples are used that cross the assessment themes of health, biodiversity, transport and critical infrastructure. A third-pass risk and adaptation assessment is an opportunity to get more specific regarding hazards, risks and locations. It is certain to be incomplete and provides a gap analysis to scope out the information and expertise needed to carry out a more detailed third-pass risk assessment. The first case study examines risks that are considered to be a priority in the short term, e.g. SLR, while the second case study addresses the longer term climate risks associated with urban heat. The need for quantitative and qualitative information in practice is stressed and some data sources for Ireland are provided.

4.1 Data Repositories and Resources

In the context of planning for the future, past climate records are inadequate and information is now required on how climate change may affect key climatic parameters and on the effects of these changes in Ireland (O'Dwyer and Gault, 2017). Many countries have established web-based information resources for addressing climate risk and adaptation planning. These websites provide scientific information and decision support frameworks. Different evaluation tools are demonstrated using case studies. The Climate Ireland website (https://www.climateireland.ie/#!/) brings together climate data and projections, scientific research, policy and tools to assess vulnerability and develop the most appropriate adaptation strategies. The website also provides a directory of online resources.

Table 4.1 lists some datasets available at the national or regional level that are useful for initial first-pass assessments. The Open Data Portal publishes an increasing collection of public service data. The National Environmental Data Map (NED-Map), produced by the National Economic and Social Council (NESC, 2014), provides a comprehensive list of environmental data sources. Costs for current and future hazards and responses can be difficult and expensive to determine. Because of the high cost of studies to obtain these costs, indicative costs and ranges may suffice for initial assessments of risk and adaptation actions. Specific local data may also be available. Some sector-specific information is held by different operators and may not be readily available to those outside these organisations; this could be because of the presence of information silos or because of commercial sensitivity. Building trust and sharing such information is a prerequisite for integrated adaptation planning.

4.2 Case Study 1: Urban Heat

While opportunities associated with increased hours of sunshine and warmer temperatures were identified in Table 3.4, the UHI effect was identified as being a medium- to long-term risk for Ireland, i.e. over 21–50 years.

While urban areas will generally experience the same exposure to climate change as the surrounding regions, the process of urbanisation results in changes in land, land cover and land surface characteristics that subsequently modify the climate at the neighbourhood scale, moisture exchanges and ecosystem services, promoting heat trapping and storage. The UHI effect contributes to increased levels of heat stress and mortality among vulnerable populations (e.g. the elderly and the young) and this is particularly relevant for Ireland's population, which is aging faster than other parts of Europe (CSO, 2016). In addition, the UHI effect has implications for thermal energy behaviour and the performance of buildings, resulting in a greater (lesser) energy demand for cooling (heating) (Mirzaei and Haghighat, 2010; Santamouris, 2014; Pyrgou *et al*., 2017).

In this case study, the effect of increasing average temperatures and increased frequency of heatwaves

Table 4.1. Examples of potential data sources in Ireland

Data source	Website
The Irish Climate Information Platform (ICIP)	www.climateireland.ie
The Central Statistics Office (CSO) is Ireland's national statistical office with a mandate for the collection, compilation, extraction and dissemination for statistical purposes of information relating to economic, social and general activities and conditions in the state	https://www.cso.ie/en/
Ireland's Open Data Portal, which publishes Irish public sector data in open, free and reusable formats	https://data.gov.ie/
The National Environmental Data Map (NED-Map), which is produced by the National Economic and Social Council and provides an overview of Irish environmental data sources	http://files.nesc.ie/nesc_reports/en/NESC_136.pdf
The National Parks and Wildlife Service provides mapping of SACs, SPAs and nature reserves	https://www.npws.ie/maps-and-data
Previous EPA-funded research on climate change	https://www.epa.ie/pubs/reports/research/climate/
Government department reports and sector adaptation frameworks	
The OPW makes available a range of maps, hydrometric data resources and technical specifications and guidance notes to assist stakeholders and inform policy and planning. These include flood hazards, flood defence and drainage schemes in place and real-time and archived water level data	https://www.opw.ie/en/flood-risk-management/mapsdataresourcesandspecifications/
The Hospital In-Patient Enquiry (HIPE) scheme of the Healthcare Pricing Office is a health information system designed to collect clinical and administrative data on discharges, admissions and length of stay for Irish hospitals. Activity-based funding for hospitals requires the production of costings for inpatient and day-case activity carried by hospitals. The first price list (2019) has recently been issued	http://www.hpo.ie/
Statistics for energy use in Ireland and a geocoded building energy rating database	https://www.seai.ie/
Met Éireann	https://www.met.ie/climate/climate-change
All-Island Research Observatory	http://airo.maynoothuniversity.ie/
National Biodiversity Data Centre	https://www.biodiversityireland.ie/
National Flood Hazard Mapping	http://www.floodmaps.ie/
Environmental Sensitivity Mapping	http://airo.maynoothuniversity.ie/mapping-resources/airo-research-maps/environmental-research-projects/environmental-sensitivity

on the Eastern and Midland Regional Assembly (EMRA) was explored in the context of population health and economic productivity. This case study draws on existing information and data to conduct a third-pass risk analysis, focusing on the EMRA. Particular attention was paid to the impacts on health and productivity, although impacts on the other inter-related climate change themes raised in Chapter 3 are also noted.

4.2.1 Projections

In Ireland, the annual average surface air temperature has increased by approximately 0.8°C over the last 110 years (Dwyer, 2012). There has been an increase in the number of warm days (temperatures over 20°C) and a decrease in the number of frost days (temperatures below 0°C) per year in the period from 1961 to 2010 (Dwyer, 2012). Current climate change projections for Ireland for mid-century (2050) indicate an increase of 1–1.6°C in the mean annual temperature compared with the period from 1981 to 2000, with the largest increases seen in the east of the country (Nolan, 2015). Projections for 2100 are for temperature increases to range between +1°C and +3°C compared with the 1961–2000 average (Nolan, 2015). Matthews *et al*. (2016) found that summer temperatures as warm as those during the 1995 heatwave could occur almost 50% and 90% of the time by the end of the 21st century, depending on which climate change scenario is used (the different scenarios are presented in section 1.4).

To assess potential future health-related impacts as a result of the planned future development of urban areas and projected climate change, Paranunzio *et al*. (2020) employed a land use change model and urban climate model to account for the effects of potential future land use and the UHI effect on temperature changes in the Greater Dublin Area. The potential future health impacts were assessed on the basis of the Universal Thermal Climate Index (UTCI), which categorises exposure to thermal stress into 10 categories, ranging from extreme heat to extreme cold stress. Each category is defined by a specific range of UTCI values and is representative of the load caused by physiological and thermoregulatory responses of the human body when responding to the actual environmental conditions (Błażejczyk *et al*., 2013). As illustrated in Figure 4.1, for RCP 8.5 and the month of July (the warmest month based on the 30-year climate normal period in Ireland; Paranunzio *et al*., 2020), exposure to high temperatures is expected to increase significantly in the 2050s across the Greater Dublin Area and is most extensive in County Dublin because of the UHI effect. Figure 4.2 shows the projected number of hours of exposure to conditions that could be conducive to heat stress on the population during the month of July for the 2050s, with the highest level evident in Dublin City and the surrounding urban areas.

4.2.2 Potential impacts

Increased temperatures and health

Projections suggest that heat-related impacts on human health could become commonplace by mid-century and, as discussed earlier, hot summers are associated with increased mortality rates. Health effects from exposure to heat range from minor illnesses to increased risks of hospitalisation and death. Heatwaves are associated with increased mortality and morbidity rates (cardiac and respiration issues; Robine *et al*., 2008; Christidis *et al*., 2015). Heat can often exacerbate existing medical conditions and contribute to the increased risk of mortality. A number of factors may modify or contribute to the mortality risk from heat, including social status, individual behaviour, extent of urbanisation and the influence of air pollution, which may increase during hot periods. Given the complex interactions between these factors, the mortality count for each heatwave is very dependent on the event location, timing and past experiences of the local populations (Mitchell *et al*., 2016).

Human populations who live in cities at high latitudes and cities that currently experience severe cold

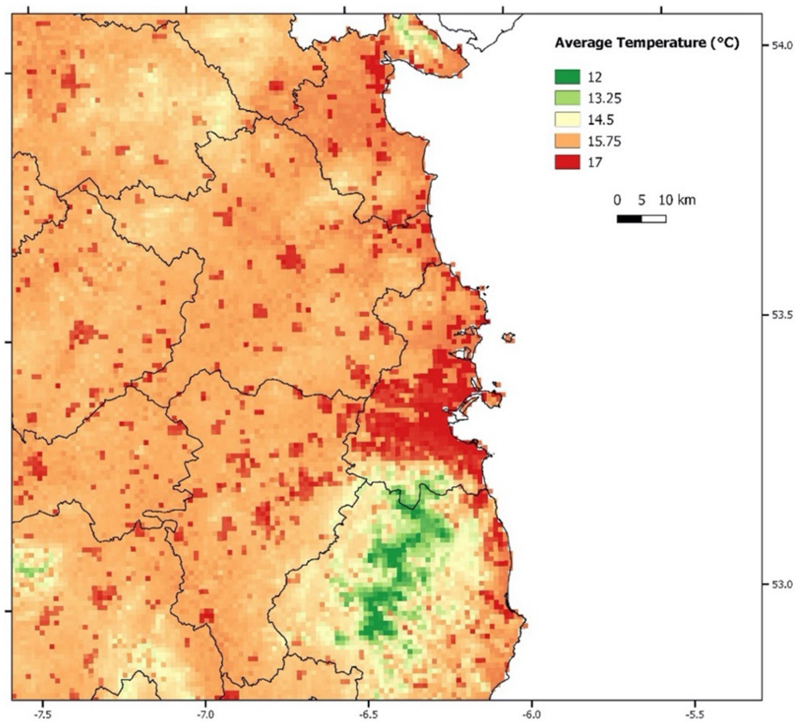

Figure 4.1. Monthly average air temperature for the 2050s under RCP 8.5 in the month of July across the EMRA. Values in the legend refer to the upper threshold in each class. Source: Paranunzio *et al*. (2020).

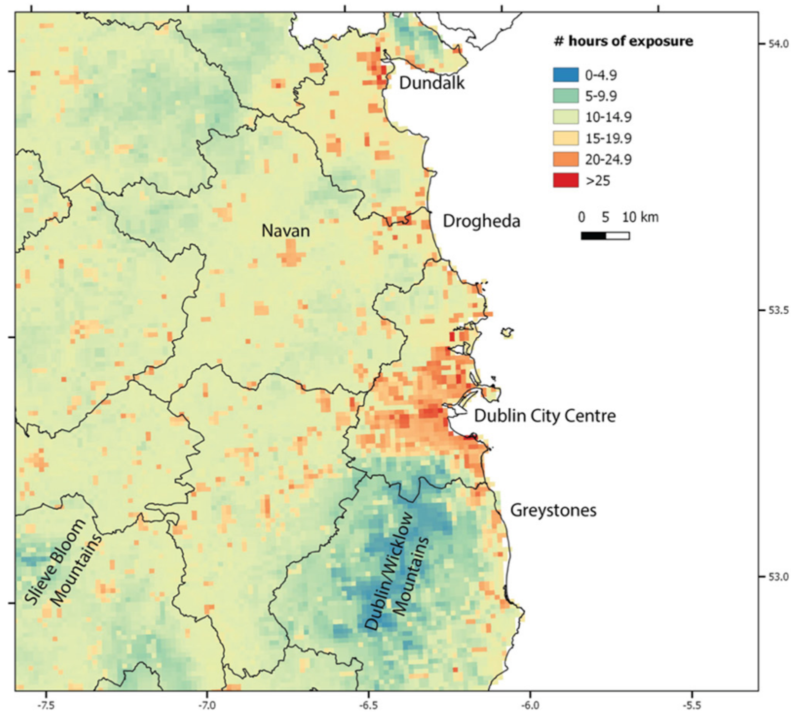

Figure 4.2. Exposure to heat in the 2050s in terms of (strong) heat stress based on the UTCI under RCP 8.5 in the month of July across the EMRA. Source: Paranunzio *et al.* (2020).

winters can experience some benefits from the UHI effect during winter, such as cheaper heating costs, improved outdoor comfort, fewer road weather hazards, more benign conditions for plant growth and animal habitats (Stewart and Oke, 2012) and increases in tourism (Dwyer, 2012). However, cooler northern European cities seem to be more vulnerable to increased summer warming and heatwaves than southern European cities, which have experience of adapting to the intense summer heat (Ward *et al*., 2016). Increasing temperatures and increasing urbanisation of the world's population will exacerbate the negative issues associated with the UHI effect.

Increased temperatures and economic productivity

Cities contribute a large proportion of national gross domestic product (GDP; Hallegate and Corfee-Morlot, 2011). Economic activity in Ireland is concentrated in Dublin City, which accounts for over 45% of Ireland's GDP. The Greater Dublin Area accounts for over 50% of Ireland's GDP (2014);[6] for comparison, London accounts for 23% of the UK's GDP. Therefore, heatwaves in Dublin have the potential to impact economic productivity at the macro level.

Seppänen and Fisk (2006) conducted a meta-analysis of 26 studies of office workers and showed a decrease in performance in temperatures above 23°C and an increase in performance in temperatures up to 20–23°C. They calculated a 10% reduction in performance at 30°C compared with productivity at the neutral inflection point (21.6°C). They also conducted a meta-analysis of the impact of temperature on worker health and found a 12% increase in the intensity of sick building syndrome symptoms[7] per 1°C increase in temperature above 22.5°C, which may indirectly result in reduced productivity because of absence from work. Burke *et al*. (2015) found that there is a global annual average temperature threshold for productivity of 13°C. Economic growth (change in GDP per capita) increases as the annual average temperature

6 http://www.dublinchamber.ie/business-agenda/about-dublin (accessed 22 June 2020).

7 Symptoms include skin and eye irritation, headaches, lethargy, irritability, poor concentration and a stuffy or runny nose. Sick building syndrome is suspected when people working in particular buildings experience these sorts of symptoms more often than is usual and the symptoms increase in severity with time spent in the building and improve over time or disappear when away from the building.

increases, until the 13°C optimum. Beyond this threshold, productivity decreases with increasing temperature, gradually at first but at an increased rate of decline at higher temperatures. The result was tested with different cohorts and found to be robust. If this rule of thumb is applied to Ireland, where the 30-year annual average temperature at Dublin airport is 8.8°C, it would seem that there is space before temperatures reach a critical inflection point and impact on economic growth.

The correlation between economic output and temperature is particularly apparent in poorer countries (Dell *et al*., 2012). In poor countries, high temperatures reduce economic output and growth rates – the effects are wide-ranging, with reductions in agricultural and industrial outputs and effects on political stability (Dell *et al*., 2012). However, Burke *et al*. (2015) found that wealth and technology do not protect rich countries from the negative economic impacts of high temperatures and that they have a similar negative response to high temperatures.

High and extreme temperatures are an emerging issue for individual businesses. Employers have a general duty under the Safety, Health and Welfare at Work Act 2005 (HAS, 2005) to ensure the safety, health and welfare of employees. At the moment, under Irish legislation, the minimum temperature for an internal workplace is 17.5°C (16°C for rigorous physical work), but no maximum temperature is prescribed. This is likely to change as high temperatures occur more frequently, especially in urban areas. Employers and employees will need to determine who bears the cost of lost workdays because of excessive heat in the same manner that there are currently negotiations over days lost to stormy or snowy weather.

4.2.3 Adaptation options

Adaptive capacity is influenced by demographic characteristics (age, gender, family status), health status (pre-existing illnesses), access to resources, support and information (e.g. with regard to heat protection measures) and mobility. Often referred to as heat risk factors, these determine sensitivity to heat and need to be considered in determining the coping and adaptation capacity of the population. The following list details a number of potential adaptation options to cope with increased temperatures in relation to health in an urban area:

- Heatwave early warning systems (HEWSs) with response plans are an approach to reducing the human health consequences of heatwaves (Lowe *et al*., 2011). A HEWS for Ireland has been suggested by Pascal *et al*. (2009).
- Traditional materials used for rooftops and roadways are very effective absorbers of heat. Solar-reflective (also known as high-albedo) alternatives lower the surface temperature so that there is less surface-to-air heat transfer. Solar-reflective materials maintain low surface temperatures in sunlight. After initial installation, these alternatives are mainly passive (Bretz *et al*., 1997).
- Increased urban green space is recognised as an important component of UHI mitigation strategies (Stewart and Oke, 2012; Doick *et al*., 2014). Alexander *et al*. (2016) found that design interventions that maintain the ratio of vegetation-to-artificial surfaces at ≥9:16 reduce the impact of the UHI effect. The many benefits arising from green spaces can be examined from a multitude of angles, e.g. mitigation of the UHI effect, promotion of local ecosystems and ecosystem services (including better management of water courses), improved air quality, and health and well-being effects (Dempsey *et al*., 2018).
- Air conditioning is a response with socio-economic aspects of access and affordability. It also interacts negatively with mitigation efforts related to energy use and GHG emissions.

Since 2003, improved emergency responses (an outcome of national planning) have reduced mortality rates during heatwaves (Mitchell *et al*., 2016). The likelihood of facing more and more intense heatwaves, together with potentially increasing vulnerabilities (e.g. an aging population), calls for efforts to be made to minimise the adverse effects of heatwaves. These efforts should be proportionate to the risks expected in Ireland (Pascal *et al*., 2013). At present, suggested adaptation actions are as follows:

- Introduce a HEWS with targeted messaging:
  - Define the triggers that would initiate a HEWS for Dublin.
  - Promote appropriate behaviours in the population.
  - Alert health professionals as a first and essential step to limit the adverse impacts of heatwaves.

  - Optimise the HEWS to target the groups that are most at risk.
- Ensure that green areas, and tree canopies in particular, are maintained and, if possible, increased:
  - Concentrate on areas with a high deprivation index and a high population density. Urban areas should produce a green area/tree strategy, e.g. the Dublin City Tree Strategy (Dublin City Council, 2016).
- Further investigate the use of reflective materials in public infrastructure:
  - Can these materials be incorporated into upgrades and new builds?
- Further investigate the use of reflective materials in the private built environment:
  - Can these materials be incorporated into upgrades and new builds?
  - Is there an option to nudge design towards the use of reflective materials?

A HEWS early warning system and increased green space are two low-regret-type options[8] that can be immediately applied. The feasibility and timing of implementing adaptive building regulations should be investigated further and built into a pathways approach for this hazard.

4.2.4 Summary

This third-pass risk and adaptation assessment provides detailed information and site-specific data on the exposure and vulnerability of the Greater Dublin Area to heat-related impacts. However, it is important to note that, although projected changes in both land use and climate have been accounted for, data in relation to projected changes in socio-economic and demographic conditions are at the regional scale. To further explore the risks posed, there is a need to develop relationship models between increased air temperatures and productivity and health impacts so that the economic outcomes of health and performance can be integrated into cost–benefit calculations. In general, impacts, vulnerability and adaptation to climate change have been the topic of significantly less research than mitigation at the city scale (Hallegate *et al*., 2011). Burke *et al*. (2015) found that there had been little investment in adaptation to heat in either poor or rich countries (166 countries) over the 50-year period from 1960 to 2010. Many economic components, such as labour availability and primary agricultural production, have been found to have concave non-linear relationships with temperature: there is a threshold at which the positive influence of temperature changes direction to become detrimental.

4.3 Case Study 2: Sea Level Rise – Quantifying Economic Impacts

The risks associated with SLR were identified as a priority in the short to long term as part of the first-pass assessment and this is particularly the case when considered in the context of projected increases in the frequency and intensity of coastal storms.

Currently, coastal flooding and erosion pose a serious threat for Ireland because most of Ireland’s population and infrastructure are concentrated on the coast and in the coastal cities of Dublin, Cork, Limerick and Galway. Current exposure to coastal flood risk is determined by a number of factors, including topography, the frequency and intensity of storm surges and extent of SLR. For Ireland, projected changes in sea level in combination with expected increases in storm activity will result in an increased risk of coastal flooding. This increased risk extends not only to those areas already at risk of coastal flooding but also to new areas that are currently not considered at risk.

This case study examines SLR on the south-east coast, from south of Dublin to Rosslare Harbour, under the themes presented in Chapter 3. The major risks associated with SLR are increased flooding and permanent inundation of low-lying coastal areas, increased erosion of beaches and cliffs, and degradation of coastal ecosystems (Dwyer, 2012). Locally, salinisation effects may be important (Richards and Nicholls, 2009; Hinkel *et al*., 2010).

4.3.1 Projections

Global mean sea levels are projected to rise by up to 1.1 m by the end of the century (IPCC, 2019; Nolan, 2015). It is already acknowledged that, with the

8 No-regret actions are cost-effective now and under a range of future climate scenarios and do not involve hard trade-offs with other policy objectives. Low-regret actions are relatively low cost and provide relatively large benefits under predicted future climates.

current conservative estimates of SLR, sea levels will continue to rise after 2100. Furthermore, with the increased rates of glacier and ice sheet melting now being observed, rises above 1 m by 2100 are entirely feasible.

Although the east coast receives only about 20% of the wave energy levels occurring on western Atlantic coasts, coastal erosion rates on “soft” (sediment-dominated) coasts (e.g. sandy systems and glacial sediments of the east coast) reach average values of 0.2–0.5 m/year, commonly rising to 1–2 m/year on southern and eastern coasts (Devoy, 2008). Coastal erosion and flooding as a result of extreme weather events already constitute a serious risk to transport infrastructure located on the coast and result in damage to infrastructure, service disruption and significant financial costs (DTTAS, 2017). The Irish Coastal Protection Strategy Study (OPW, 2010) has produced strategic coastal flood and erosion hazard maps to establish a baseline for the current level of hazard. This study has also produced predictive coastal flood extent and flood depth maps and identified that the coastal flood hazard exists predominantly in or near coastal settlements, with seven primary areas of potential coastal flood risk identified (OPW, 2010). A strategic-level erosion assessment was therefore undertaken along the study coastline to estimate the likely future position of the coastline in the years 2030 and 2050.

4.3.2 Potential impacts

Sea level rise on the eastern coast presents risks under a number of the themes outlined in Chapter 2. Three types of transport represent critical infrastructure along the south-east coast of Ireland: rail, sea and road. The Irish rail track from Dublin to Rosslare carries both passengers and freight, and the southern Dublin Area Rapid Transit (DART) system carries passengers, mainly people travelling for work and education purposes on a daily basis. Ongoing and projected changes in sea level and projected changes in the occurrence and intensity of storm surges have been identified as high-priority impacts of climate change for rail transport (DTTAS, 2017). It is estimated that the coastline will continue to recede and could potentially undermine the existing rail corridor before 2030. The DART system is also vulnerable. Closing the DART line because of flooding for 1 day in 2018 affected 80,000 passengers (Melia, 2018).

Rosslare Port is a Tier 2 Port of National Significance connected to the Irish rail line. The port provides ferry services to the UK and mainland Europe. In total, 1,218,000 tonnes of goods were exported and 948,000 tonnes were received in 2017. The Port is also an important portal for tourism, accommodating 844,000 passengers in 2017 (excluding cruise ship passengers) (CSO, 2017). Given its links with France, Rosslare Port will be a crucial port post Brexit. (DTTAS, 2017). The risks to port infrastructure are described in the following quotation:

> damages to port infrastructure, navigations and safety equipment; damages to vessels while in port and impacts on safety of passengers while embarking, in transit, and disembarking. Storm activity can also cause issues in relation to the channels leading into ports becoming blocked with large amounts of sand silt and other materials driven by storm activity. In addition, changes in sea level will have impacts on dredging requirements at ports, positive or negative depending on local circumstances, and implications for natural scouring capability at estuarial ports. (DTTAS, 2017, p. 45)

Breaks in rail, road or port-based transport will interrupt supply chains and cause disruption for businesses and consumers. It is estimated that the requirement for storage facilities will double because of climate-related supply chain disruptions.

Sea level rise: quantifying economic impacts of potential sea level rise scenarios on Irish coastal cities

The following bottom-up approach explores the potential economic impacts of SLR on the Irish coast, with a special focus on coastal cities. An estimate of the potential economic impact has been developed through the use of an Irish digital terrain model (DTM),[9] in conjunction with a geocoded directory of Irish property addresses and historical flood insurance claims data. Potential land inundation impacts are also presented. The headline results indicate that

9 Irish 20-m medium-scale resolution DTM produced by the Irish EPA.

approximately 350 km² of land is vulnerable under SLR of 1 m, increasing to 600 km² under SLR of 3 m. Potential economic costs relating to property insurance claims are in the region of €1.1 billion under the 1-m scenario, increasing to over €2.1 billion under the 3-m scenario (Flood, 2012; Flood and Sweeney, 2012).

Initially, the area of potential vulnerability to SLR was calculated from the DTM projections, and any areas in the modelling that were not part of the coastline or that were part of existing river networks were manually discounted from the calculations. The An Post GeoDirectory was then used to examine potentially vulnerable addresses. This directory is a collaboration between the Irish Post Office Service and Ordnance Survey Ireland and provides close to 2 million accurate geographical addresses up to July 2009 (Fahey and Finch, 2009). Figure 4.3 identifies the total numbers of vulnerable addresses (residential and commercial) in each coastal county under six SLR scenarios (of 0.5 m, 1 m, 2 m, 3 m, 4 m and 6 m).

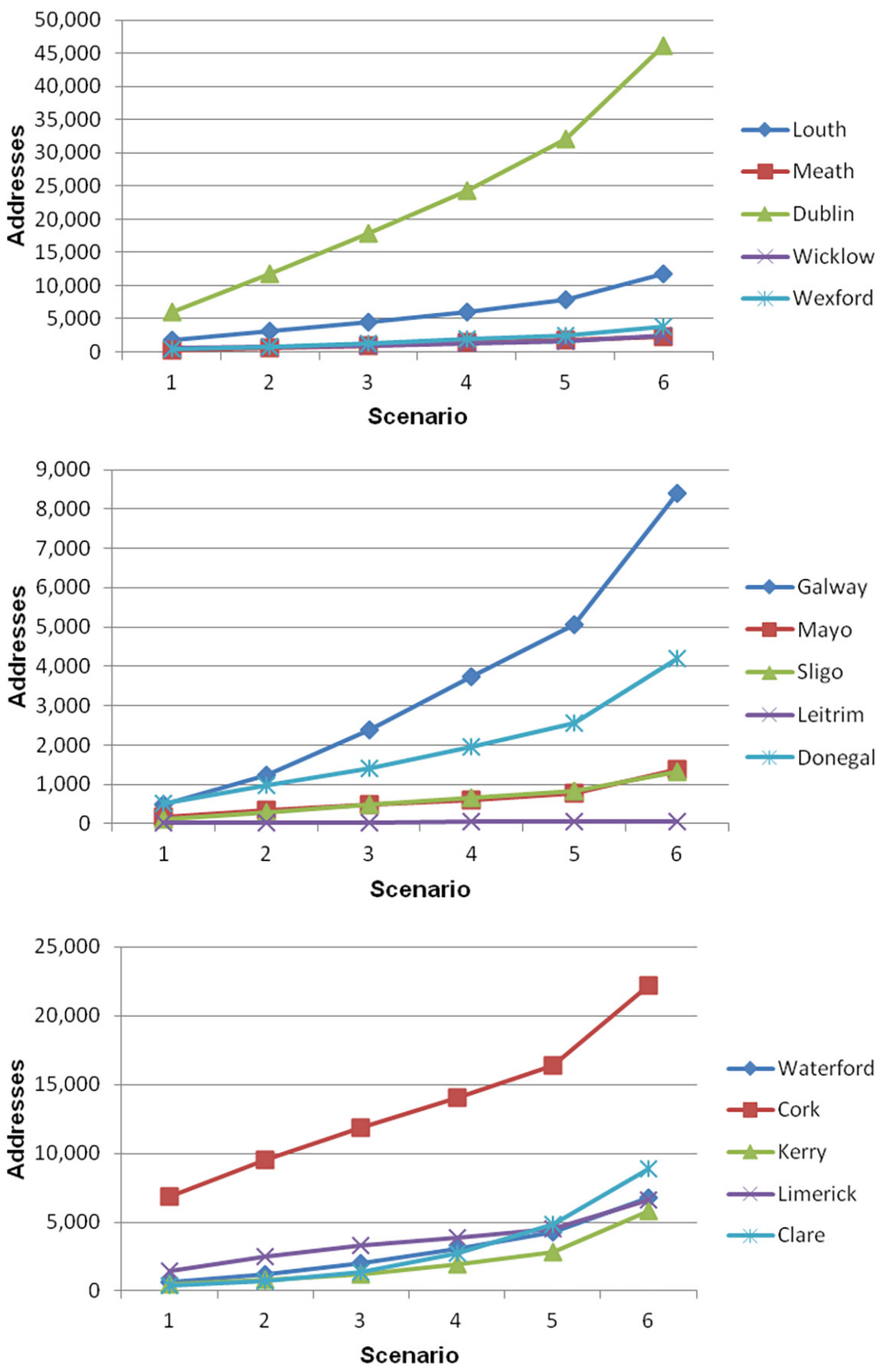

Figure 4.3. Total numbers of vulnerable addresses in each coastal county under six SLR scenarios. Scenarios 1–6 represent SLR of 0.5 m, 1 m, 2 m, 3 m, 4 m and 6 m, respectively.

Figures released by the Irish Insurance Federation (IIF) in 2010 provided the insurance costs relating to flood damage from the 2009 substantial November flood events (IIF, 2010). Additional figures relating to the October 2011 flood events were released in January 2012 (IIF, 2012). The 2009 and 2011 flood events are the two most costly flood events recorded by the IIF. The majority of the 2009 November flood costs were realised in Munster, the west and the Midlands. The three worst-hit counties were Cork, Galway and Clare. The majority of the October 2011 flooding took place on the east coast, with most of the flooding occurring in Dublin. Using the figures from both events as a guideline, a rough average estimate of the cost per claim was calculated for residential and commercial properties. The average insurance claim per residential household across both flood events was approximately €16,500, with the Munster floods averaging €16,591 per claim and the Leinster floods averaging €16,421 per claim. The average insurance claim per commercial property across both flood events was approximately €75,000. The average claim for commercial properties in the two flood events varied significantly, with the Munster floods averaging €103,114 per claim and the Leinster floods averaging €47,162 per claim. An average insurance claim for joint-use properties of €46,000 was estimated by averaging the residential and commercial claims. Table 4.2 provides estimates of the potential insurance costs in each coastal county under the six SLR scenarios, employing the methodology outlined above.

4.3.3 Adaptation options

At a very broad scale the adaptation responses of coastal communities and infrastructure under threat from SLR can be classified as protection, accommodation and managed retreat (Nicholls and Cazenave, 2010).

- Protection could be provided by hard engineering – a sea wall or a rock revetment – or soft engineering – annual beach nourishment.
- Accommodation involves introducing planning regulations to reduce vulnerability, such as zoning (including setback buffers), building codes and resilient design.
- Retreat involves relocation, abandonment and demolition.

Table 4.2. Potential insurance claims for all coastal counties under the six SLR scenarios

	SLR scenario (€M for all claims)					
Province/county	**0.5 m**	**1 m**	**2 m**	**3 m**	**4 m**	**6 m**
Leinster						
Louth	43	80	111	153	197	294
Meath	5	1	22	30	37	46
Dublin	151	303	458	607	806	1194
Wicklow	16	22	28	39	50	77
Wexford	11	21	36	54	72	114
Munster						
Waterford	13	23	38	61	78	121
Cork	267	361	439	510	582	737
Kerry	11	1	31	46	68	148
Limerick	50	75	97	112	130	184
Clare	10	19	34	65	119	226
Connaught						
Galway	12	33	58	89	125	234
Mayo	5	10	13	16	21	37
Sligo	4	11	18	24	29	47
Leitrim	0	0	1	1	1	1
Ulster						
Donegal	18	35	48	66	82	132
Total	**617**	**995**	**1431**	**1872**	**2399**	**3592**

The topography to the east of the east coast rail corridor prevents coastal realignment or retreat. Accommodation is not an option for critical infrastructure that by definition must be reliable. Unreliability would have the impact of reducing passenger numbers, leading to reduced income and increased carbon-intensive road traffic as commuters opt for more reliable routes. There appears to be a necessity to invest in protection measures and Irish Rail has been progressive with this task and developed, with Arup, a decision support tool to assess infrastructure performance in the face of coastal erosion and flooding.

4.3.4 Summary

The vast majority of economic assessments of potential climate change impacts are framed at a global or regional level. Global GDP costs relating to climate change impacts have been estimated to range from in the region of 1% to 10% of global GDP per annum, or from approximately €480 billion to approximately €4.8 trillion per year (based on global GDP at current prices). The figures vary greatly as each analysis uses different economic models that consider different sectors and impacts and use different discount rates. By demonstrating the economic impact of SLR and storm surges on coastal properties, the monetary values provided in this coastal vulnerability analysis provide policy incentives to address and adapt to climate change. However, they do not offer help in deciding when to adapt, to what extent to adapt and where exactly adaptive measures should be prioritised. In summary, decision-makers need to recognise the value of no- or low-regret and win–win adaptation options and avoid actions that foreclose or limit future adaptations. It is also wise to work in close partnership with the local communities involved and address risks associated with present climate variability and extremes.

5 Concluding Remarks and Recommendations

It is essential that adaptation at the national, regional and sectoral scales is underpinned by robust fit-for-purpose and appropriate CCRA methodologies and outputs. The tiered assessment approach to CCRA employed and illustrated in this report highlights a viable methodology for identifying and assessing climate change risk in Ireland, within existing limitations (e.g. data and personnel). It also makes clear that climate risk assessment and management is an iterative and ongoing process that needs constant revision and reassessment as new knowledge, information and resources become available.

The tiered nature of the assessment provides an iterative approach that supports adaptive management approaches and can be considered as learning by doing, allowing decision-making communities to increase their understanding of the range of risks (first-pass assessment), prioritise these risks through further analyses of their impacts on strategic goals and directions (second-pass assessment) and develop a detailed understanding of priority risks through a third-pass assessment. Importantly, this tiered approach helps identify research gaps to support future and more complex assessments of climate risk. These include the interlinked and cascading nature of climate risks across society. The approach is also compatible, complementary and open for future integration into other climate action initiatives, e.g. the Climate Ireland platform.

Stakeholder engagement was a vital activity over the course of this project. It involved engaging with representatives from Climate Ireland, Ireland’s CAROs, government departments, local authorities and the DCCAE, through one-to-one conversations and workshops. Such engagement helped to identify and assess future hazards and risks and provided context for the climate projections and socio-economic and demographic information employed as part of this research.

The project results indicate that, at the national scale, priority climate change hazards and associated risks have been identified and are primarily associated with SLR and increases in the frequency and intensity of coastal storms in the short term. In the longer term, risks associated with increasing average temperatures and heatwaves have been highlighted. For some areas and sectors, there now exists enough information to conduct third-pass risk assessments, enabling the identification of climate-related risk across projected scenarios of climate change (RCPs) and the identification and assessment of site-specific adaptation actions.

5.1 Recommendations

- Adaptation planning is an iterative process that involves learning by doing; a tiered approach supports the iterative nature of adaptation planning. For example, Ireland’s first round of local and sectoral adaptation plans and strategies is based on a first- to second-pass assessment approach. Current adaptation plans should be evaluated against the CCRA process. To address the barriers to implementation of site-specific adaptation actions, there is a requirement to progress to third-pass assessment methodologies.
- CCRAs and third-pass assessments are based on detailed information and data. There is a requirement to continue to advance the knowledge base, especially in relation to spatially and temporally specific impact studies (observed and projected), vulnerability analysis and adaptation option appraisal.
- Future development and policy decisions will have implications for levels of exposure to climate hazards and associated risks. There is a requirement to include approaches, adapted for Irish conditions, that consider changes in populations and demographics, such as those developed using shared socio-economic pathways, to account for human factors in risk assessment.
- Enhance the engagement of all stakeholders, including the wider community at the local level, and promote the co-production of knowledge and solutions to maximise acceptance of mitigation and adaptation measures.

- There is a clear need to fully inculcate CCRA into the Climate Ireland platform and into climate action mainstreaming in general. CCRA can both inform the identification of adaptation options and, through application of evaluation approaches, e.g. CBA, facilitate the process of deciding on the most favourable adaptation options.

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Glossary

Adaptation	Adaptation is the process of adjustment to actual or expected climate change and its effects. In human systems adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems human intervention may facilitate adjustment to expected climate change and its effects
Adaptive capacity	Adaptive capacity describes the ability of a sector to design or implement effective adaptation measures, using information on possible future climate change and extreme weather to moderate potential damage, take advantage of opportunities or cope with the consequences
Baseline	A baseline is a state against which a change is measured. For example, a “current baseline” is made up of observable, present-day conditions
Capacity	Capacity is the combination of all of the strengths and resources available within a community, society or organisation that can reduce the level of risk or the effects of a disaster. It can also be described as capability
Capacity building	In the context of climate change, capacity building describes developing the right skills and capabilities to help countries adapt to climate change. This also includes helping them to mitigate their greenhouse gas emissions
Climate	The climate can be described simply as the “average weather”, typically over a period of 30 years. It can include temperature, rainfall, snow cover or any other weather characteristic
Climate change	Climate change refers to a change in the state of the climate. It can be identified by changes in average climate characteristics that persist for an extended period, typically decades or longer
Climate change scenario	A climate change scenario is a plausible description of a change in climate by a certain time in the future. These scenarios are developed using models of the Earth’s climate. Climate models are based on scientific understanding of the way that the land, ocean and atmosphere interact and their responses to factors that can influence climate in the future, such as greenhouse gas emissions
Climate proofing	Climate proofing is concerned with protecting development investments and outcomes from the impacts of climate change. It reduces the vulnerability of projects by analysing the risks that climate change poses and taking steps to counteract them
Confidence	In a scientific context, confidence describes the extent to which the findings of an assessment are considered valid, based on the type, amount, quality and consistency of the evidence
Ecosystem services	The benefits to society from resources and processes provided by ecosystems can be described as ecosystem services. These can include pollination and disease control, the provision of food and fuel, regulation of the flow of water through land to both prevent flooding and filter clean drinking water, and the aesthetic and amenity value of the countryside

Exposure	Exposure represents the presence of the elements at risk (e.g. buildings, infrastructure, environments, livelihoods, species) that could be adversely affected by climate change
Extreme weather	Extreme weather includes unusual, severe or unseasonal weather or weather at the extremes of the range of weather observed in the past
Greenhouse gases	Greenhouse gases are gases whose presence in the atmosphere traps energy radiated by the Earth; this is called the greenhouse effect. These gases can be produced through natural or human processes. CO_2 is the most important greenhouse gas. Other greenhouse gases are methane, fluorinated gases, ozone and nitrous oxide. See also Section 1 of the Climate Action and Low Carbon Development Act 2015 for a legal definition (DCCAE, 2015a)
Hazard	A hazard refers to a physical phenomenon that has the potential to cause damage and losses to humans and natural systems
Impact	In the context of climate change, an impact is the effect of climate change (e.g. flooding, rails buckling, etc.)
Likelihood	Likelihood is the chance of an event or outcome occurring, usually expressed as a probability
Loss and damage	Loss and damage are the negative or residual impacts of climate change that occur in spite of adaptation, mitigation, disaster risk reduction and other measures taken to prevent or reduce expected effects
Mitigation	Mitigation describes action taken to reduce the likelihood of an event occurring or to reduce the impact if it does occur. This can include reducing the causes of climate change (e.g. emissions of greenhouse gases), as well as reducing future risks associated with climate change
Model	A model is a representation of how a system works. It can be used to understand how the system will respond to inputs and other changes
Natural adaptive capacity	Natural adaptive capacity describes the ability of a species or natural system to adjust to climate change and extreme weather to moderate potential damage, take advantage of any opportunities and cope with the consequences
No-regret (adaptation) options	No-regret (adaptation) options are activities that provide immediate economic and environmental benefits and continue to be worthwhile regardless of future climate change. They would be justified under all plausible future scenarios, including those without climate change
Planned adaptation	Planned adaptation is the result of a deliberate policy decision and most likely includes action that is required to return to, maintain or achieve a desired state
Probability	Probability is used to describe the chance or relative frequency of particular types of event occurring. It can also include sequences or combinations of such events
Projection	A projection is any plausible description of the future and the pathway that leads to it. A specific interpretation of a “climate projection” is an estimate of future climate developed using models of the Earth’s climate. Projections are not predictions. Projections include assumptions, for example about future socio-economic and technological developments, which might or might not happen. They therefore come with some uncertainties

Radiative forcing	Radiative forcing is the difference between sunlight absorbed by the Earth and energy radiated back to space
Resilience	Resilience is the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining their capacity for adaptation, learning and transformation
Risk	Risk is the potential for consequences when something of value is at stake and when the outcome is uncertain. Risk results from the interaction of hazard, exposure and vulnerability
Risk analysis	Risk analysis develops an understanding of each risk, its consequences and the likelihood of those consequences occurring; it is expressed as qualitative, semi-quantitative or quantitative data
Risk evaluation	Risk evaluation involves making a decision about the level of risk and the priority for attention
Risk identification	Risk identification is a systematic process to understand what could happen, how, when and why
Risk management	Risk management involves putting in place plans to avoid unacceptable consequences of risks
Scenario	A scenario is a plausible description of a possible future state of the world. These include specific assumptions about how aspects of the world might change, e.g. economies, social trends, changes in technology and environmental changes, based on the best understanding available
Sensitivity	Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damage caused by an increase in the frequency of coastal flooding because of SLR)
Severe weather	Severe weather refers to any dangerous meteorological phenomenon with the potential to cause damage, serious social disruption or loss of life
Transformation	Transformation is a change in the fundamental attributes of natural and human systems. Transformation can reflect strengthened, altered or aligned paradigms, goals or values to promote adaptation for sustainable development
Uncertainty	Uncertainty is the degree to which a value or relationship is unknown. Uncertainty can result from a lack of information or from disagreement about what is known or even knowable. Uncertainty may originate from many sources, such as quantifiable errors in data, ambiguously defined concepts or terminology, or uncertain projections of human behaviour
Vulnerability	Vulnerability is characterised by the different elements at risk from a given hazard intensity. Vulnerability includes economic, social, geographical, demographic, cultural, institutional, governance and environmental factors. Vulnerability encompasses concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt

Abbreviations

CARO	Climate Action Regional Office
CBA	Cost–benefit analysis
CBD	Convention on Biological Diversity
CCAC	Climate Change Advisory Council
CCRA	Climate Change Risk Assessment
CEA	Cost-effectiveness analysis
CLC	CORINE Land Cover
CORINE	Coordination of Information on the Environment
DART	Dublin Area Rapid Transit
DCCAE	Department of Communications, Climate Action and Environment
DTM	Digital terrain model
EMRA	Eastern and Midland Regional Assembly
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
HEWS	Heatwave early warning system
HSE	Health Service Executive
IIF	Irish Insurance Federation
IPCC	Intergovernmental Panel on Climate Change
MCA	Multi-criteria analysis
NAF	National Adaptation Framework
NHA	Natural Heritage Area
NWRP	National Water Resources Plan
OPW	Office of Public Works
RCP	Representative concentration pathway
RDM	Robust decision-making
SAC	Special Area of Conservation
SDG	Sustainable Development Goal
S.I.	Statutory Instrument
SLR	Sea level rise
SPA	Special Protection Area
UHI	Urban heat island
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UTCI	Universal Thermal Climate Index
WFD	Water Framework Directive

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.

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National Risk Assessment of Impacts of Climate Change: Bridging the Gap to Adaptation Action

Authors: Stephen Flood, Shona Paterson, Ellen O'Connor, Barry O'Dwyer, Hester Whyte, Martin Le Tissier and Jeremy Gault

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

Identifying Pressures

Ireland's climate is changing in line with global trends and this trend is expected to continue and intensify into the future. Climate change will have wide-ranging effects on all aspects of Ireland's society, environment and economy. The likely future impacts of climate change in Ireland in terms of physical changes relate to temperature, precipitation and sea level rise, with the most prominent risks associated with projected increases in extreme weather conditions and an increased likelihood of river and coastal flooding. Preliminary economic assessment of these risks has highlighted those risks with the potential to cause substantial disruptions to economic activity. These include the costs of flooding, disruptions to essential services (including threats to critical infrastructure), climate impacts outside Ireland, and effects of climate change on Irish society.

Informing Policy

A clear message to the international community emerging from the recent United Nations Climate Change Conference (COP21) in Paris was the need for accelerated action to build climate resilience through risk-sensitive planning, and to advance risk assessment and management at local, national, subregional and regional levels. This recommendation is echoed in Ireland's National Adaptation Framework (NAF), which identified risk assessment as a prerequisite for strategic planning for climate change, and in how Ireland is preparing to respond to climate change. Reflecting the requirements of Ireland's NAF, the Climate Action Plan requires consideration of climate change impacts. Such information supports decision-making in relation to appropriate mitigation and adaptation actions for existing planning for future development by highlighting potential future impacts, vulnerabilities and risks.

Developing Solutions

Adapting Ireland to existing and future climate change impacts requires information not only on exposure to climate change and impacts but also on the vulnerability of people and communities to these impacts. Climate risk results from the interaction of hazards, exposure and vulnerability. While hazards are related to the physical aspect of risks (natural variability and anthropogenic climate change), exposure and vulnerability encompass socio-economic processes This national Climate Change Risk Assessment adopts a tiered assessment approach to capture the range of climate-driven risks across Irish society. This tiered approach provides a methodology to carry out an effective climate risk screening process in the face of a range of constraints linked with finances, personnel, time and data availability. In order to facilitate policy cohesion and alignment with Ireland's NAF, this report presents its findings according to the NAF's four themes: natural and cultural capital, critical infrastructure, water resources and flood risk management, and public health. The impacts of climate change will have direct relevance to the achievement of planning and development objectives and priorities within these themes.

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