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

Report No. **301**

Adaptive Responses to Climate Impacts (ARC): Costing the Impacts of Climate Change on the Irish Economy and Assessing the Options for Adaptation, with a Specific Focus on the Role of Key Stakeholders

Authors: Justin Doran, Thomas McDermott, Paul Kilgarriff, Swenja Surminski and Mauricio Perez Alaniz

www.epa.ie

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.

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

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

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

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

Our Responsibilities

Licensing

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

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

National Environmental Enforcement

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

Water Management

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

Monitoring, Analysing and Reporting on the Environment

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

Regulating Ireland's Greenhouse Gas Emissions

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

Environmental Research and Development

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

Strategic Environmental Assessment

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

Radiological Protection

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

Guidance, Accessible Information and Education

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

Awareness Raising and Behavioural Change

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

Management and structure of the EPA

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

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

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

EPA RESEARCH PROGRAMME 2014–2020

Adaptive Responses to Climate Impacts (ARC): Costing the Impacts of Climate Change on the Irish Economy and Assessing the Options for Adaptation, with a Specific Focus on the Role of Key Stakeholders

(2015-CCRP-DS.10)

EPA Research Report

Prepared for the Environmental Protection Agency

by

University College Cork, National University of Ireland Galway, London School of Economics and Political Science, Teagasc and University of Limerick

Authors:

Justin Doran, Thomas McDermott, Paul Kilgarriff, Swenja Surminski and Mauricio Perez Alaniz

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

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

ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2014–2020. The EPA Research Programme is a Government of Ireland initiative funded by the Department of Communications, Climate Action and Environment. It is administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research. We gratefully acknowledge funding for this project from Ireland's EPA and the Irish Department of Housing, Planning and Local Government, as well as institutional support from the Grantham Research Institute at the London School of Economics and the Environmental Research Institute at University College Cork.

The authors would like to acknowledge the members of the project steering committee, namely Mark Adamson (Office of Public Works), Margaret Desmond (EPA), Leigh Wolfrom (Organisation for Economic Co-operation and Development), John O'Neill (Department of Communications, Climate Action and Environment) and Karen Roche (Project Manager on behalf of EPA Research). We are very grateful to the following people for providing helpful comments, inputs, support and data over the course of the ARC project: Paul Alexander, Paul Bolger, Mark Conroy, Chris Duffy, Caroline Kousky, Georgina Kyriacou, Helen McMahon, Cathal O'Donoghue, Barry O'Dwyer, Gregg Patrick, Saji Varghese, Seamus Walsh and Jeremy Ward. A special word of thanks goes to all those who participated in our various stakeholder engagement activities, especially those who took part in our two stakeholder workshops. Excellent research assistance was provided by Joel Hankinson, Bunmi Ipinnaiye and Peter Lambert. Any remaining errors or omissions are entirely the responsibility of the authors.

EPA RESEARCH PROGRAMME 2014–2020
Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-84095-868-3 November 2019

Price: Free Online version

Project Partners

Justin Doran
School of Economics
University College Cork
Cork
Ireland
Tel.: + 353 21 490 18 82
Email: justin.doran@ucc.ie

Thomas McDermott
School of Business and Economics
National University of Ireland, Galway
Galway
Ireland
Tel.: +353 (0)91 494 327
Email: thomas.mcdermott@nuigalway.ie

Paul Kilgarriff
Luxembourg Institute of Socio-Economic Reseach (LISER)
Maison des Sciences Humaines 11
Luxembourg
Tel.: +352 58 58 55 965
Email: paul.kilgarriff@liser.lu

Swenja Surminski
Grantham Research Institute on Climate Change and the Environment
London School of Economics and Political Science
London
UK
Tel.: +44 (0)20 7107 5027
Email: s.surminski@lse.ac.uk

Mauricio Perez Alaniz
Kemmy Business School
University of Limerick
Limerick
Ireland

Contents

Acknowledgements ii

Disclaimer ii

Project Partners iii

List of Figures and Tables vi

Executive Summary vii

1 Context for the Research 1

1.1 Background and Motivation for the ARC Research Project 1

1.2 Aims and Objectives of the ARC Research Project 2

1.3 Motivation: Focus on Managing Flood Risk and Adaptation to Climate Change 2

1.4 Policy Context 3

1.5 Outline of the Project Structure 4

2 Summary of Research Findings 6

2.1 The Impact of a Flooding Disruption on the Spatial Distribution of Commuters' Income 6

2.2 Growing Exposure to Climate Change: A Spatial Socio-economic Analysis of Exposure to Flooding in Cork City 8

2.3 The Effect of Flood Risk on House Prices in Cork City 11

2.4 Fit for the Future? The Reform of Flood Insurance in Ireland: Resolving the Data Controversy and Supporting Climate Change Adaptation 13

2.5 How Normative Interpretations of Climate Risk Assessment Affect Local Decision Making – An Exploratory Study at the City Scale in Cork, Ireland 14

References 19

Abbreviations 22

Appendix 1 List of Project Outputs and Dissemination Activities 23

List of Figures and Tables

Figures

Figure 2.1.	Additional commuting costs as a result of flooding as a percentage of work income	7
Figure 2.2.	Population change by area of flood risk	10
Figure 2.3.	Flood risk, by type and annual exceedence probability, for the Lee catchment	12
Figure 2.4.	Different stages of the “decision cycle”	16

Tables

Table 2.1.	Categories of “severity” of exposure to flood risk at the ED level	10
Table 2.2.	Population of EDs in the Lee catchment in 2016 according to flood risk exposure category	10

Executive Summary

Summary of Key Findings from the Research

Building on the literature on adaptation to climate change and extensive stakeholder engagement, this project identifies several interacting factors that should be considered in designing efficient climate change adaptation strategies. These correspond to questions about how much adaptation should be undertaken, and at what cost, and a related set of questions about who bears the burden of the costs associated with climate change impacts and how exposure to risk is evolving over time and across space and socio-economic groups. Our research also deals directly with policy issues related to determining the appropriate role for the private sector, and in particular the role of insurance as a key mechanism to cope with the risk of climate change, and policy issues related to the process of translating risk assessment into adaptation action at the local level.

We present new evidence on the costs of weather-related disruptions to transport; changes in exposure to flood risk; the impacts of flood risk on house prices; and the distribution of exposure to risk and costs of particular events across socio-economic groups in Ireland. Second, we address the policy context directly by examining how local decision making both responds to risk assessment and, in turn, affects exposure to risk, as well as how private sector responses affect the distribution of the cost burden across public and private actors, with a focus on the potential role of insurance as a tool for managing climate risk.

These factors will not only enable a better identification of the potential benefits of adaptation but also encourage risk ownership and engagement. It is also proposed that obtaining better estimations of the direct and indirect costs of climate change, and their distribution across socio-economic groups, will enable the public and private sector to make more informed decisions.

The different elements of our research project are largely embedded and interdependent on each other. Increasing commuting costs in the presence of severe weather events is exacerbated by current demographic and economic trends and lack of appropriate public transport and infrastructure. Focusing on adaptation can only partially address these costs. Similarly, in the case of insurance, insurers point to underlying causes for high premiums or unavailable insurance cover and call for better planning in order to avoid developments in high-risk areas. Nevertheless, cities benefit from these developments and their sustainability may be affected if stringent planning regulations act to restrict the supply of residential or commercial property. Property markets should, in theory, provide price signals to home purchasers about the value of risks; as our analysis shows, however, such risk information may not always be conveyed in prices, particularly in city locations where demand is high and supply is restricted. The high share of renters in the riskiest parts of Cork city, noted in our analysis, may also play a role here.

The research outputs are organised into the following five inter-related themes:

1. the costs of transport disruptions due to flooding;
2. evolving exposure to flood risk;
3. the effect of flood risk on house prices;
4. the role of insurance as a risk-coping mechanism;
5. the decision-making process for flood risk management at a local city level.

The findings related to these five thematic areas are discussed in more detail in the remainder of this summary report. Details of the research conducted can be found in the accompanying “technical” report for the project (which is available from http://erc.epa.ie/safer/iso19115/displayISO19115.jsp?isoID=3177), as well as in the outputs from the project listed in Appendix 1.

Policy Recommendations

As well as the new empirical evidence presented in relation to transport disruptions, exposure to flood risk and the effect of flood risk on house prices, the project outputs also reflect on policy recommendations in two specific areas:

1. **Flood insurance.** The key to sustainable flood insurance is improved data sharing between government, insurers and other sectors that hold data about flood risks. Our analysis concludes that better data sharing may help to address problems of unaffordable or unavailable flood insurance, which are currently experienced by some homeowners and businesses in Ireland. However, the report warns against "short-term, stop-gap efforts" to prop up the existing insurance system, likening such attempts to treating the symptom without treating the cause – increasing flood risk. Only a "significant increase in efforts to address the underlying risks and to minimise future risks" will secure affordable, available and sustainable insurance for the future. The report *Fit for the Future? The Reform of Flood Insurance in Ireland: Resolving the Data Controversy and Supporting Climate Change Adaptation* points out that the recent discussions about the Flood Insurance Bill and the new National Adaptation Framework provide a chance to propose a "radical shift" away from the current approach to flood risk data and towards greater transparency about flood risk for government, insurers, businesses, homeowners and other sectors that make decisions affecting future flood resilience. The report calls for Ireland's government, insurers, utility companies, banks, property developers and all other sectors that own data on flood risks to collaborate on the creation of a publicly available platform where data can be shared and accessed. In addition to information on insurance protection in areas at risk and government research data, other sectors can provide valuable information on flood risk, for example on the extent of protection measures for properties and maintenance levels of drainage systems. The proposed data hub would create transparency about risk levels and could be used to support risk reduction efforts, as well as help to prevent future risk creation. It could encourage insurers to set fair and transparent premiums that recognise risk reduction measures. It could also be used by government to provide short-term relief to support homeowners and businesses currently struggling to secure affordable insurance and to target flood protection measures at areas that are at most risk. The data-sharing platform should also be used by other sectors when making decisions, for example in planning where and how to build new properties or infrastructure to increase future resilience to flooding and address underlying flood risks. The report suggests that Ireland could become a "front runner" by committing to a broad data platform involving other sectors. Although data-sharing platforms between government and insurers exist in other countries, none has yet included data owned by other sectors.

2. **Decision making.** Urban areas already suffer substantial losses in both economic and human terms from climate-related disasters. These losses are anticipated to grow substantially, in part as a result of the impacts of climate change. We investigate the process of translating climate risk data into action at the city level. We apply a commonly used decision framework as our backdrop and explore where in this process climate risk assessment and normative political judgements intersect. We use the case of flood risk management in Cork city in Ireland to investigate what is needed for translating risk assessment into action at the local city level. Evidence presented is based on focus group discussions at two stakeholder workshops and a series of individual meetings and telephone discussions with stakeholders involved in local decision making related to flood risk management and adaptation to climate change in Ireland. Respondents were chosen on the basis of their expertise and/or involvement in decision-making processes locally and nationally. Representatives of groups affected by flood risk and flood risk management/adaptation efforts were also included. The Cork example highlights that, despite ever-more accurate data and an increasing range of theoretical approaches available to local decision makers, it is the normative interpretation of this information that determines what action is taken. The use of risk assessments for decision making is a process that requires normative decisions, such as setting "acceptable risk levels" and identifying "adequate" protection levels, which will not succeed without broader buy-in and stakeholder participation. Identifying and embracing these up front could strengthen the urban adaptation process – this may, in fact, turn out to be the biggest advantage of climate risk assessment: it offers an opportunity to create a shared understanding of the problem and enables an informed evaluation and discussion of remedial action.

1 Context for the Research

1.1 Background and Motivation for the ARC Research Project

Climate change is likely to lead to physical changes in temperature and precipitation and sea level rise (SLR; IPCC, 2013). The impacts of these changes on future weather patterns in Ireland have recently been summarised by Desmond *et al*. (2017):

- Observations suggest that Ireland is already experiencing the effects of anthropogenic climate change.
- Projections for Ireland indicate a significant warming of, on average, between 1°C and 1.6°C by mid-century, with annual precipitation expected to decrease on average, with the sharpest reductions in summer (0–20%) (Gleeson *et al*., 2013; Nolan, 2015).
- Projections of changes in weather extremes are much less certain. However, an intensification of rainfall patterns (more incidences of high- and low-flow periods; Coll *et al*., 2014) and increasing seasonality in hydrological regimes is expected. For example, a 20% increase in river flows is predicted for the majority of catchments by mid- to late century, along with summer decreases of over 40% (Murphy and Charlton, 2007; Steele-Dunne, 2014).
- Projections indicate slightly fewer, but more intense, storms (Nolan, 2015), although uncertainty around details remains high (Matthews *et al*., 2016).
- Mean sea levels have been rising at a rate of approx. 3.5 cm per decade since the early 1990s – earlier tide gauge records show SLR of 1–2 mm per year for Ireland's coasts, indicating the expected acceleration in SLR (Devoy, 2008). Further mean SLR of 55–60 cm is expected by 2100 [based on Intergovernmental Panel on Climate Change (IPCC) representative concentration pathways (RCPs) of 2.6 and 4.5 and other medium-scale climate warming scenarios; see Lowe *et al*., 2009]. Regional SLR, allowing for isostatic components, will add approx. 40 cm to SLR in the south-west of Ireland by 2080–2100 (Devoy, 2008).

These changes will have economic implications, bringing both risks and opportunities for the Irish economy and for society more broadly. Investment decisions and economic activity more generally will be sensitive to both changes in average conditions and changes in the frequency of extremes (Stainforth *et al*., 2007). It has been noted by Desmond *et al*. (2017, p. ix) that "extreme events, such as severe flooding, droughts and heat-/cold waves, can have important socio-economic consequences. Changes in their frequency and intensity are therefore of particular interest to policymakers and stakeholders" (Nolan *et al*., 2013; Nolan, 2015; O'Sullivan *et al*., 2015).

Equally important for informing policy is to understand current exposure and vulnerability to these hazards; how these will evolve in response to changing risk profiles and new information about risk; and how policy can influence these processes. These questions are the focus of this report.

We take an explicitly social science perspective: the socio-economic impacts of climate change will be determined by a combination of the changing hazard (e.g. changes in weather patterns, including the distribution of extreme weather events) and changes in exposure and vulnerability to those hazards. We do not focus on the physical effects of climate change, such as changes in average temperature and precipitation patterns and effects on the distribution of more extreme weather events (including storms, floods and droughts), which have been reviewed and discussed extensively elsewhere (see, for example, Nolan, 2015; Desmond *et al.*, 2017). Rather, our focus is on the socio-economic determinants of exposure and vulnerability to (changing) climate-related hazards, on estimating the costs of climate-related risks and on appropriate policy responses to these evolving risks.

We take a two-pronged approach to this. First, we conduct novel data analysis and present new evidence on the costs of weather-related disruptions to transport; changes in exposure to flood risk; impacts of flood risk on house prices; and the distribution of exposure to risk and costs of particular events across socio-economic groups in Ireland. Second, we address the policy context directly by examining how local

decision making both responds to risk assessment and, in turn, affects exposure to risk, as well as how private sector responses affect the distribution of the cost burden across public and private actors, with a focus on the potential role of insurance as a tool for managing climate risk. This policy-oriented part of the project involved extensive engagement with stakeholders at a national and local level.

An important theme across our work in this project is the response to risk information, both from the general public (as captured, for example, in the effects of flood risk on house prices) and from policymakers (as captured in our analysis of the local decision-making process for flood risk management), as well as from the private sector (as captured in the estimation of risk and the provision of flood insurance). Other themes highlighted in the research project are engagement and risk ownership. Current approaches to risk assessment and estimation of climate damages may be inadequate to encourage stakeholders to engage in, and support, efficient adaptation strategies, for example because of limited information on the distribution of costs across different socio-economic groups. How to encourage private agents to act on adaptation, as well as engage with, and support, public initiatives to adaptation, is high on current policy and research agendas.

1.2 Aims and Objectives of the ARC Research Project

This project sets out to estimate the costs of climate impacts for Ireland and to explore policy responses for managing climate risks, with a particular focus on the issue of flooding. The analysis presented here goes beyond risk assessment to estimate the costs of climate impacts, including indirect costs associated with extreme weather events, and how exposure to these events has evolved over time, as well as the distribution of costs and exposure across space and across different socio-economic groups, considering how this can assist with designing adaptation strategies.

This research aims to bridge the gap from vulnerability and impact assessments to the formulation of evidence-based local adaptation plans, i.e. moving from phase 1 to phase 2 of the adaptation approach adopted under the National Climate Change Adaptation Framework 2012 (DECLG, 2012) and the European Union's (EU) Strategy on Adaptation (EC, 2013). This is achieved by combining state of the art empirical analysis with stakeholder engagement locally, across the private sector and nationally. The Adaptive Responses to Climate Impacts (ARC) project involved an integrated approach, ensuring that research efforts were guided by stakeholder needs and that the end result provides decision-relevant information to stakeholders that will have impact beyond the life of the research project.

1.3 Motivation: Focus on Managing Flood Risk and Adaptation to Climate Change

Much of our report focuses on flood risk, as the context for both our empirical analysis and our policy-oriented analysis. It is important to note here the distinction between managing current risks, for example those associated with flooding, and adaptation to changes in risk, for example associated with climate change. Our analysis necessarily relies on data related to current risk profiles and historical flood events, as is standard in the empirical literature on estimating climate impacts. These observational data are required to estimate the relationship between current or historical weather events and various socio-economic outcomes of interest. These estimated relationships can then be combined with projections of future weather patterns under climate change to generate projections of future impacts and costs associated with climate change.[1] Similarly, policy challenges encountered in managing current risks will be relevant to the capacity for adaptation to future risk (or changes in risks) due to climate change. Indeed, as we detail in our analysis of the local decision-making process, climate change adds an additional layer of complexity to an already difficult public policy challenge in terms of managing flood risk.

Our focus on flood risk is motivated by the following observations:

1 It is, of course, important to note that the costs of climate change relate to the additional costs incurred as a result of changes in the frequency or intensity of an extreme weather event, over and above the costs that would be experienced in the absence of climate change.

- Large potential costs – flooding imposes substantial costs on governments, businesses and people (Hammond *et al.*, 2013). Across Europe, flood damage resulted in average annual losses of €4.2 billion between 2000 and 2012. This is expected to rise in the future, with an estimate of €23.5 billion of losses by the year 2050, compared with an average of €4 billion in 2010 (Jongman *et al*., 2014). In Ireland, the potential costs of an increase in extreme weather events have been demonstrated by recent floods and storms, including, for example, floods in Cork in 2009, which resulted in insurance claims estimated at €244 million,[2] and severe winter storms in 2013/2014, which caused damage to public infrastructure estimated at €69.65 million (NDFEM, 2014). More recently, Hurricane Ophelia, which struck Ireland in October 2017, was expected to have caused damage costing anywhere from €500 million to €1.5 billion, according to media reports at the time of the event.[3]
- Flooding has been identified as one of the main threats to Ireland from climate change [see, for example, the Environmental Protection Agency's (EPA) 2012 State of the Environment report (Lehane and O'Leary, 2012) and Desmond *et al*., 2017].
- Public intervention (adaptation) will be required, from spatial planning and development policies to flood protection measures and insurance.
- Public finances are exposed to the costs of clean-up and recovery following flood events.
- The interactions between stakeholders – national and local government, residents and business owners, as well as the insurance industry – are perhaps most complex for flood risk (relative to other types of climate risk) and thus require further attention.
- Flood risk also cuts across many sectors of the economy, from infrastructure (including transport, energy, communications and water) to the built environment, business, health and tourism, and is especially relevant for the insurance industry.

Well-planned early adaptation has been shown to save lives and money in the medium to longer term (Oreskes *et al*., 2010; Tanner and Rentschler, 2015). However, designing optimal or efficient adaptation strategies is not straightforward. In the case of flood risk, climate change adds a layer of complexity to an already challenging area of public policy. Managing flood risk requires public policy intervention as well as business and community engagement and buy-in (Atreya *et al*., 2013). As already mentioned, flood risk affects many sectors of the economy, from infrastructure (including transport, energy, communications and water) to the built environment, business, health and tourism. Flooding events also have a direct impact on people's economic welfare, imposing disruptions to everyday life, including work, and having long-term effects. Public intervention to manage flood risk requires co-ordination with private initiatives, ranging from spatial planning and development policies to flood protection measures and insurance (Ran and Nedovic-Budic, 2016).

1.4 Policy Context

Until relatively recently, research and policy efforts in relation to climate change in Europe and Ireland have been focused on mitigation [see, for example, the National Climate Change Strategy 2007–2012 (DEHLG, 2007) and National Mitigation Plan (DCCAE, 2017)]. However, it is now clear, based on the latest scientific assessments, that some climate change is inevitable, regardless of mitigation efforts, given current emissions trajectories and the strong degree of persistence in the climate system (IPCC, 2013). Adaptation to a changing climate will therefore be required in order to minimise costs and maximise opportunities (e.g. Mendelsohn, 2012). The need for adaptation strategies has been recognised in recent European and Irish policy documents [e.g. the EU's White Paper on adapting to climate change (EC, 2009); the EU Adaptation Strategy (EC, 2013); and Ireland's National Climate Change Adaptation Framework (DCCAE, 2018)].

2 Estimate from Insurance Ireland, in current (2009) prices.

3 As reported by RTE (https://www.rte.ie/news/business/2017/1017/912865-insurance-ireland/) and the *Irish Independent* (https://www.independent.ie/irish-news/hurricane-ophelia/hurricane-ophelia-could-cause-15bn-in-damage-expert-analyst-36231210.html) (accessed 28 February 2018).

Our focus on flood risk is also motivated by recent policy documents. The EPA's 2012 State of the Environment report identified the projected impacts of climate change in Ireland, including more extreme weather conditions (including rainfall events) and an increased likelihood of river and coastal flooding (see Desmond *et al*., 2017). EU Directive 2007/60/EC on the assessment and management of flood risks requires Member States to assess flood risk and to take "adequate and coordinated measures to reduce this flood risk". The Office of Public Works (OPW) has responded to the Directive by implementing the CFRAM (Catchment Flood Risk Assessment and Management) programme. Our proposal aims to go beyond risk assessment to estimate the costs of climate impacts and considers how this can assist with designing adaptation strategies. Specifically, the project makes important contributions across three themes. First, it develops and applies a methodology to estimate the indirect costs of flooding, in this case additional costs for commuters resulting from floods in the transport network. Second, a novel methodology is proposed to assess the extent to which locations are at risk of flooding; this builds on, and improves, current approaches to estimating direct costs. Similar to the approach proposed to estimate indirect costs, socio-economic and spatial data are combined in the econometric estimation. The methodology is applied to gather a deeper understanding of exposure to flooding in Cork, Ireland's second largest city, and to estimate its costs. Finally, the role of insurance is considered, given the prominence of insurance as a key coping mechanism for flood risks.

Particularly urgent from a policy perspective is the need to avoid locking in future vulnerability in the form of infrastructure and housing developments in vulnerable locations. The literature on urban economics has demonstrated the path dependency and persistence of urban locations (e.g. Davis and Weinstein, 2002; Miguel and Roland, 2011; Michaels and Rauch, 2018), so that planning decisions made today will probably affect the level of exposure to climate risk for decades to come. For example, observing rapid recovery following large-scale urban flooding in cities around the world, Kocornik-Mina *et al*. (2015 p. 4) note that "flooding poses an important challenge for urban planning because adaptation away from flood-prone locations cannot be taken for granted even in the aftermath of large and devastating floods". However, some adaptation decisions will need to be made now, in spite of the uncertainty around climate impacts (McDermott, 2016; DCCAE, 2018). For cities vulnerable to flood risk, these issues represent pressing and critical dilemmas in terms of how to balance the desire for urban expansion – particularly the development of dense urban cores – against the requirement to manage and limit flood risk. Avoiding rising flood losses needs to be balanced with the development requirements of urban areas, in terms of both population and infrastructure, prompting calls for investment in low-carbon, climate-resilient infrastructure (OECD, 2014a). In this regard, we note the recent publication of the *Project Ireland 2040: National Planning Framework* (DHPLG, 2018) and its incorporation of the "transition to a low carbon and climate resilient economy" as one of its National Strategic Outcomes. It remains to be seen what influence the latest planning framework will have on future exposure and vulnerability to climate risk.[4]

1.5 Outline of the Project Structure

The project *"*Adaptive Responses to Climate Impacts (ARC): Costing Climate Change Impacts and Adaptation in Ireland" was conducted jointly by University College Cork (UCC) and the Grantham Research Institute on Climate Change and the Environment at the London School of Economics. The work was funded by Ireland's EPA under the EPA Research Programme 2014–2020. The project focused on several inter-related factors likely to affect the efficient design of adaptation interventions in Ireland across four work packages (WPs):

- WP1 represents the foundation step for the project, involving an extensive literature review of academic as well as international best practice related to climate change adaptation, initial stakeholder engagement and advice from international experts, in order to frame

4 We note that our empirical analysis necessarily examines the outcomes of historical planning policies in determining exposure and vulnerability to natural hazards, whereas our policy discussion focuses on how planning policies have been implemented to date in relation to flood risk management. We also note that the National Planning Framework was published after most of the research for this project was completed.

the research agenda and methods used in subsequent analyses.

- WP2 involved extensive engagement with stakeholders on flood risk in Ireland, including the insurance industry, with a view to informing the research, guiding policy formation and disseminating research findings. This process benefitted from the active participation of representatives of the EPA, the OPW, Met Éireann, government departments (including the Department of Communications, Climate Action and Environment, Department of Public Expenditure and Department of Finance), the European Commission, local stakeholders in Cork (including Cork City Council, as well as local business groups), representatives of the insurance industry and academic and other industry experts.
- WP3 involved the development of innovative methods for empirical estimation of the costs of climate impacts, with a focus on using novel datasets that can capture effects beyond direct asset losses; exposure to flood risk, with a focus on the dynamics of changing exposure over time and the distribution of exposure across socio-economic groups; and the impact of flood risk on house prices.
- Finally, WP4 focused on policy analysis related to two key themes: (1) the role of insurance as a key coping mechanism against weather-related risks, considering the availability and affordability of insurance in Ireland, and (2) the translation of risk assessment and information on climate change into adaptive decision making at the local (city) level. The focus on insurance is relevant for adaptation debates in Ireland and elsewhere, given its prominence as a key coping mechanism and the current debates about the insurance sector's economic and political implications.

2 Summary of Research Findings

The research conducted as part of the ARC project can be divided into two inter-related strands, with distinct methodological approaches; the first strand is based on empirical research on climate impacts, their costs and exposure and how these are distributed across socio-economic groups (see sections 2.1–2.3), whereas the second strand involves policy-oriented research with a strong focus on stakeholder engagement (see sections 2.4 and 2.5). Here, we present a summary of the key research findings from the project, based on the five distinct research themes outlined above.

2.1 The Impact of a Flooding Disruption on the Spatial Distribution of Commuters' Income

Flooding already imposes substantial costs on the economy. Costs are expected to rise in the future, both as a result of changing weather patterns due to climate change and because of changes in exposure to flood risk resulting from socio-economic trends such as economic growth and urbanisation. The UK's Climate Change Risk Assessment (DEFRA, 2012) noted that the transport network is at significant risk of flooding.[5]

Beginning with Storm Desmond in early December, and followed by Storms Eva and Frank, the winter of 2015/2016 represented the wettest winter on record for Ireland. Rainfall levels in some areas were up to 250% of normal levels, with over half of all stations recording their wettest winter on record (Met Éireann, 2016). Extensive flooding around the country caused widespread damage – hundreds of homes and businesses were flooded and thousands more were cut off by flood waters. Nationally, €1.8 million in humanitarian assistance was paid out to affected households; close to €1 million was paid to farmers; local authorities received special funding of €18 million for clean-up costs; and damage to the road network was estimated at over €100 million. In County Galway, humanitarian assistance for 162 households totalled €256,000, clean-up costs were €3.1 million and 80 houses were inaccessible. Aside from damages, the flooding also caused substantial disruptions to everyday life (350,000 customers suffered disruptions to their electricity supply and 23,000 households were placed on boil water notices). The flooding also resulted in substantial travel disruptions, in particular as a result of flooding on the road network (National Directorate for Fire and Emergency Management, 2016). For many areas of County Galway this was the second major flooding event since 2009.[6]

We estimated the costs to commuters as a result of travel disruptions caused by flooding during the winter storms of 2015/2016 in Ireland, specifically Storm Desmond. Using Galway as a case study, we simulated, for every commuter in County Galway, their commuting travel times under the status quo and during the period of the floods, and estimated the additional costs imposed on commuters, as well as how these costs were distributed across space and across socio-economic groups. The results show that those already facing large commuting costs were burdened with extra costs by the floods, with rural areas particularly vulnerable. In areas that were badly affected, extra costs amounted to 39% of earnings (during the period of disruption), with those on lower incomes suffering proportionately greater losses. Commuting was found to have a regressive impact on income distribution, increasing the Gini coefficient from 0.32 to 0.38. Although Storm Desmond was considered a one in 100-year event, because of climate change we can expect such events to occur with substantially greater frequency in the future. However, we note that the event magnitude/probability would have varied across different catchments.

5 Perhaps surprisingly, transport disruptions as a result of extreme weather events – specifically flooding – received little or no mention in a recent report by Desmond et al. (2017) on the state of knowledge on climate change impacts for Ireland (see, in particular, section 3.1 and Table 3.1 on impacts on critical infrastructure). This suggests a gap in the current knowledge base for Ireland.

6 According to records available from the floods.ie website, maintained by the Office of Public Works (accessed in May 2019).

Commuting in Ireland already involves substantial costs, in the form of the monetary costs of travel (ticket prices or the cost of fuel and other running costs for car drivers), as well as the welfare cost of the lost time spent commuting (Vega *et al*., 2017). Our research makes use of road closure data collected by Galway County Council in the aftermath of Storm Desmond (December 2015). The data that we used detail road status (open, closed, passable, one lane only) and are time stamped, enabling us to observe which segments of the road network were affected on a particular day at a particular time. The data cover a 17 work day period of disruption (from 9 December 2015 to 5 January 2016). These data were combined with the OpenStreetMap road network, the Central Statistics Office (CSO) POWSCAR (Place of Work, School or College – Census of Anonymised Results) 2011 and SMILE (Simulated Model of the Irish Local Economy) (O'Donoghue *et al*., 2012). Using this combined dataset we simulated for every commuter in County Galway their commuting time and cost of commute (combined monetary and time costs) under the status quo and separately for each day (morning and evening) of the flooding period.

Observing commuting patterns before the flooding event, we note that those on the outer Galway city commuting belt already have high commuting costs. Some of these areas also overlap with the areas worst affected by the floods, according to our data. Direct commuting costs for the worst affected areas ranged from €278 to €680 per commuter over the 17-day period. In terms of commuting times, for some commuters the flooding involved an extra 30–60 minutes per day of travel time. When we included the time costs, that is, monetary compensation for the extra time spent travelling, the total extra cost of the disruption represented some 10–38% of the daily working wage of the average commuter in the worst affected areas (this result is illustrated in Figure 2.1).

When looking at the distribution of commuting costs associated with flooding across income groups, we found that higher earners are relatively less impacted. Specifically, for every extra €1000 in disposable income, we estimate that the additional cost of the flood as a percentage of income decreases by approximately 3.6%. This income effect also holds when controlling for other socio-economic characteristics (such as age, education and housing tenure). Our results therefore suggest that the effects of the travel disruption due to flooding are regressive, that is, the welfare effect is relatively more severe for those on lower incomes.

On aggregate, we estimate the total cost of the disruption to commuting in County Galway during the

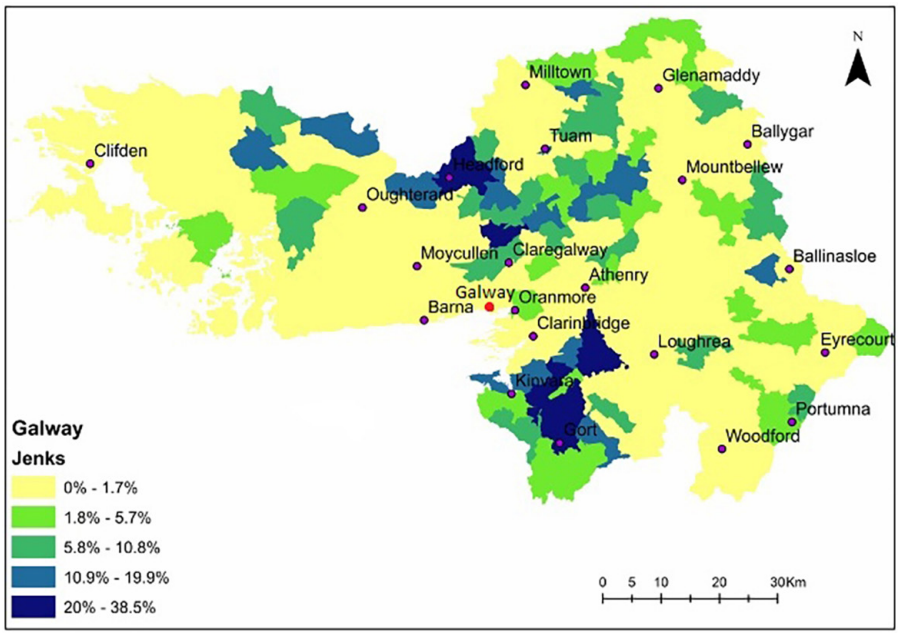

Figure 2.1. Additional commuting costs as a result of flooding as a percentage of work income. Additional commuting time and distance travelled as a result of flooding were converted into monetary costs and are presented as a percentage of total work income over the 17-day period.

flooding at €3.8 million. This estimate assumes that every commuter in Galway actually travelled to work each day during the flooding. However, our estimates are conservative in that our model cannot account for delays on non-flooded routes because of additional volumes of traffic or for disruptions to commuters travelling between Galway and origins/destinations outside the county. We also do not count any costs imposed on commercial vehicles, disruptions to business activity or supply chains, etc.

This research makes use of advanced commuting models, spatially rich flooding data and simulated income data. It illustrates a novel method whereby the indirect costs of extreme weather events and their distributional impacts across space and socio-economic groups can be measured, something that can be replicated for other hazards and across other locations. Our research builds on the literature by utilising observational data as opposed to predictive flood hazard mapping. Although measuring the disruption is not novel in itself, this aspect is added to by monetising the disruption and calculating the impact on income and inequality. Previous studies focusing on the impact of flooding on socio-demographic and economic characteristics are hampered by a lack of income data at a detailed spatial scale (Ford *et al*., 2015). This study uses a spatial microsimulation model, SMILE, to simulate income for each commuter (Morrissey *et al*., 2013). By combining these simulated data with travel-to-work data it is possible to examine the socio-economic characteristics of commuters impacted by the disruption.

Although Storm Desmond was considered a one in 100-year event, a near real-time attribution analysis found that such extreme rainfall was already up to 40% more likely because of the effects of human-induced climate change experienced to date, that is, events like this are now a one in 72-year event (van Oldenborgh *et al*., 2015). With further warming, these risks will probably multiply (IPCC, 2012, 2013). In short, we can expect events like this to occur with substantially greater frequency in the future. Understanding the full economic costs of these extreme events is an important first step in preparing for a future with increased weather risk.

The findings highlight the essential role of planning policies as an integral part of adaptation to climate change. Poor planning, without regard to climate risks, not only places property in harm's way – in the case of building in flood hazard zones – but also has the potential to increase vulnerability to transport disruptions, when poor spatial planning has resulted in an over-reliance on long-distance commuting. We have demonstrated here the very real and substantial welfare effects for those impacted by disruptions. In addition, the effects appear to be regressive: those on lower incomes suffer proportionately greater losses, whereas those living in rural areas are more at risk of travel disruptions given their longer average commuting times and the lack of public transport alternatives. This research lends further support to the calls for more sustainable models of spatial development planning that take account of the welfare costs of commuting generally and of exposure to hazard and disruption. In this regard it is encouraging to see the inclusion of the transition to a low-carbon and climate-resilient society as part of the new *Project Ireland 2040: National Planning Framework* (DHPLG, 2018). These are themes we return to later in this report.

2.2 Growing Exposure to Climate Change: A Spatial Socio-economic Analysis of Exposure to Flooding in Cork City

Picking up on the theme of planning and exposure to flood risk from the previous section, here we present the results of an analysis of exposure to flood risk in Cork city in a spatial context, with a particular emphasis on how exposure has evolved over time and on the distribution of risk across space and across socio-economic groups.

Flood risk in Ireland is increasing because of socio-economic trends and climate change. Although expected changes in hazards (i.e. the distribution of extreme weather events) as a result of climate change have been examined in detail elsewhere, less attention has been paid to changes in exposure over time. Where socio-economic trends have been assessed, this has tended to be at a spatially aggregated scale. Using recently developed flood risk maps, we analysed changing exposure in the Lee catchment over time (1996–2016). Our results show that the populations of areas most at risk of flooding have, on average, grown faster than those in non-risk areas. These flood risk areas are also commercially dense, with

many jobs vulnerable to flooding. The risk of flooding has not deterred inward migration to the city centre, particularly from young, well-educated professionals. Our provisional damage estimates also highlight the large existing exposures, particularly in Cork city. These trends highlight the need for a small-area population projections model for Ireland to complement the hydrology and climatic prediction models.

The CFRAM study of the Lee catchment calculated the number of residential properties at risk from flooding (Halcrow, 2014). What is not yet clear is the impact of flooding on different socio-economic groups in the Lee catchment area. No previous study has investigated changes in exposure to flood risk over time across socio-economic groups. For this analysis, small-area population statistics (SAPS) data for 5 census years (1996, 2002, 2006, 2011 and 2016) were used. Measures of disposable income and "at risk of poverty", which were created using the spatial microsimulation model SMILE (O'Donoghue *et al*., 2012), were added to the analysis. Using a case study approach allows the socio-economic and demographic trends both in the flood risk zones and outside the flood risk zones to be examined.

Although it is important to increase resilience by protecting against climate change, it will also be crucial that the socio-economic drivers of flood risk are not ignored. Are we over-exposing our populations to climate change by developing and building in high-risk areas or, perhaps, is developing in a particular area creating risk elsewhere? We adopted a geographic information system (GIS) approach to examine the level of exposure to flooding in the Lee catchment in Cork.

Although climate change is increasing the risk of flood events occurring in the future, population change and increasing development are leading to increasing losses during extreme weather events (Changnon *et al*., 2000; Pielke *et al*., 2008). There is increasing population growth in urban areas. The population density of Ireland has increased from 67/km^2 in 2006 to 70/km^2 in 2016 (CSO, 2016a), with the average population density in urban areas being 2008/km^2. In Ireland, 62.7% of the population now live in an urban area. For historical reasons many cities are located on the coast or close to a river, meaning that there is an increased risk of fluvial or tidal flooding occurring. Worryingly, 1.9 million people or 40% of the population live within 5 km of the coast, and 40,000 of these live within 100 m of the coast (CSO, 2016a). In the absence of changes it will be reasonable to expect increasing losses over time.

The focus in estimating economic damages in the Lee catchment CFRAM study (Halcrow, 2014) was on the current scenario 1% (one in 100-year) annual exceedance probability (AEP) fluvial and the 0.5% (one in 200-year) AEP tidal events. In this study we adopt a similar approach; this approach tends to be the most widely used in the literature (OECD, 2014b). Using these flood extent maps we identified the level of exposure to flooding by electoral division (ED). The ED level was used as this is the lowest available level of disaggregation for past census years.[7] Rather than use the percentage area of an ED at risk of flooding, we used GeoDirectory data to estimate the percentage of buildings in an ED at risk of flooding as our proxy for the severity of exposure to flood risk at the ED level.[8] The advantage of using ED-level data is that it enables matching of socio-economic and demographic data, which allows analysis to be carried out of the distribution of flood risk across different groups and also analysis of how exposure to flood risk has changed over time.

We generated three categories of the "severity" of exposure to flood risk per ED, based on the percentage of buildings in an ED that are located in the flood risk zone (defined for our purposes as the combination of the 1% fluvial and 0.5% tidal risk zones from the CFRAM maps for Cork), as presented in Table 2.1.[9]

In 2016, more than one in five residents (22%) in the Lee catchment were living in an ED with some exposure to flood risk, as illustrated in Table 2.2. We next examine how this level of exposure has changed

7 The new small areas (SAs) have a finer level of disaggregation; however, information at the SA level is available only for the 2011 census.

8 This approach was adopted to avoid counting as "exposed to flood risk" the EDs that we observed with a portion of their physical area in a flood risk zone, but with no actual buildings located in the flood risk zone.

9 Note that these categories are all based on the same return period (the combined 1% fluvial and 0.5% tidal flood zones). The "severity" of risk here refers to the level of exposure.

Table 2.1. Categories of "severity" of exposure to flood risk at the ED level

Flood risk	% of buildings at risk
Severe	≥50
Moderate	≥20 to <50
Low	>0 to <20

Table 2.2. Population of EDs in the Lee catchment in 2016 according to flood risk exposure category

Flood risk	Population	% of population
Severe	5248	1.6
Moderate	22,228	7.0
Low	42,525	13.3
No	248,827	78.0

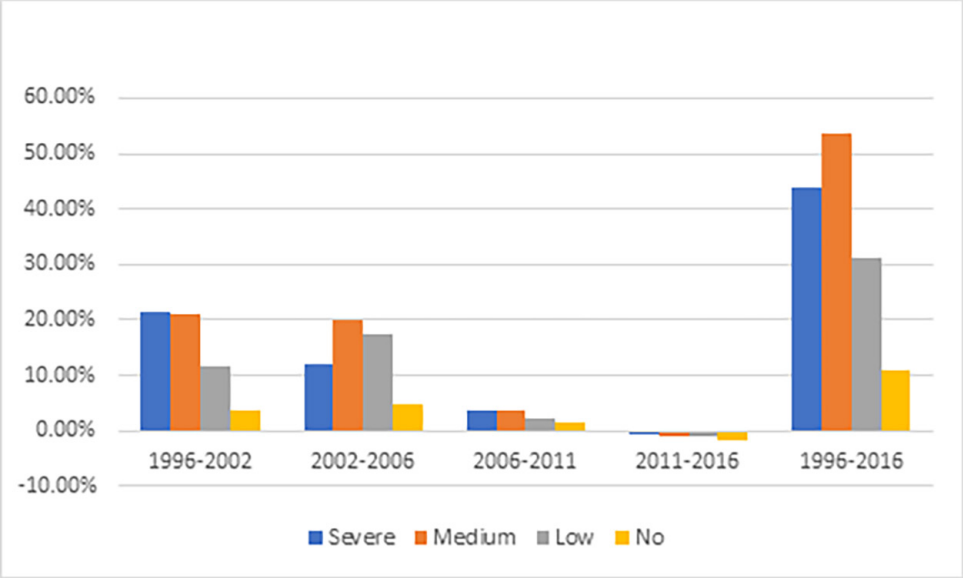

Figure 2.2. Population change by area of flood risk.

over time. Between 1996 and 2016, areas that have a severe or moderate exposure to flood risk experienced population growth rates of between 40% and 50%, whereas those areas in the Lee catchment with no exposure to flood risk grew by only 10% (Figure 2.2). A similar result was found in an OECD (2014b) study of Paris, where growth in flood risk areas is due to redevelopment of these often-attractive city centre areas.

Our analysis shows that flood risk in Cork is concentrated in the city (for workers) and towns (for residents). In terms of the socio-demographic characteristics of the risky areas, we find that the resident populations of EDs with a high exposure to flooding in Cork are relatively young: the average age for EDs in our severe risk category is 39.2 years compared with 45 years for Cork city as a whole, whereas the working age share of the population is 85% in the severe risk EDs compared with 72% for the city on average. A very high proportion of households in these areas are renters – over 70% in the highest risk areas, compared with only 26% for the city as a whole. These areas also exhibit very high work–live ratios: there are over 7 jobs per resident in the highest flood risk areas, compared with 1.6 jobs per resident for Cork city on average. This suggests that flood risk is concentrated in commercial areas, with a high density of jobs/employment, that is, areas with the greatest exposure to flooding are located in the city centre. We also find that the riskiest areas appear

to be somewhat more unequal than average. These areas have slightly higher mean disposable income (€19,763) than the city average (€18,150), but also display higher poverty rates: 20% of households in the severe risk EDs are at risk of poverty, compared with 15% in medium risk areas and 18% in areas with either low or no risk of flooding. We note that the high proportion of renters in risky areas may have implications for flood risk management policies, for example in terms of incentives to take account of flood risk and information about flood risk conveyed through house prices. This is the subject of the next section.

2.3 The Effect of Flood Risk on House Prices in Cork City

As noted previously, various parts of Cork city are exposed to fluvial and coastal flooding. Analysing the impact of flooding on house prices is relevant for several reasons. Property plays an important role in economic systems and floods are often the most common natural disaster, accounting for around 40% of all natural disasters worldwide in the period 1985–2009 (Guha-Sapir *et al*., 2010).

The mechanism used to analyse the impact of flooding on house prices is hedonic house price theory. Hedonic theory predicts that a household will choose maximising expected utility and would pay a premium to avoid flood hazards. Utility-maximising behaviour relies on the principle that flood risk information is accurate and widely known (Pryce *et al*., 2009). Insurance plays an important role in recovering from financial loss after flood events and discount rates derived from flood risk may reflect the cost of insurance. However, as Turnbull *et al*. (2013) highlight, not all costs associated with flooding events are fully insured (e.g. time, emotional cost) and discount rates may be larger than insurance premiums. In this context, a differential premium across properties according to their flood hazard should be capitalised in property prices (MacDonald *et al*., 1987). A significant amount of research has addressed the issues of modelling and determining the impact of floods on house prices; for recent examples see Cohen *et al*. (2015), Eves and Wilkinson (2014) and Zhang (2016).

The data used in this section were collated from a number of distinct datasets obtained from the CSO, which it utilises to construct its Residential Property Price Index (RPPI). Four datasets were combined:

1. Stamp duty data. The principal data source for the RPPI are the stamp duty data provided to the CSO by the Revenue Commissioners. The stamp duty data are a very rich data source in terms of providing characteristics of the buyers and sellers of properties.
2. Building Energy Rating (BER) data. A BER certificate must be presented for all residential property advertised for sale (with some very minor exceptions). As part of the BER assessment process, detailed information on the physical characteristics of a dwelling is collected, including the type of dwelling (detached house, semi-detached house, etc.) and the floor area (m^2) of the dwelling.
3. GeoDirectory. This is a dataset of all buildings in the State, created and maintained by GeoDirectory using data from An Post and Ordnance Survey Ireland (OSi).
4. Deprivation index. This is the Pobal Haase–Pratschke (HP) Deprivation Index. The Pobal HP Deprivation Index measures the relative affluence or disadvantage of each SA.

Further definitions and details of these datasets are available from the CSO (2016b).

Initially, data from the stamp duty dataset were used to provide the prices at which properties had been sold. These data are available from January 2010 to June 2017. Two dates of transaction are available from these data: the date of sale and the date that a transaction was registered. In this study we used the date of sale data. Data are also available indicating whether a property is a new build or a second-hand home and on the type of purchaser (family, investor, other). These data were merged with the CSO Pobal HP Deprivation Index indicator of deprivation at the SA level, which provides an indication of the level of deprivation of the region. As income is not available at this level, this indicator of deprivation can be taken as a proxy to provide an indication of the wealth of a region (as wealthier regions would be expected to have higher house prices). We also obtained information on the types of property sold, that is, apartment, semi-detached house, etc., and on floor area from the BER statistics. These data provided us with a list of standard determinants of variation in property prices. When we limited the data to Cork city,

this resulted in a total sample size of 11,573 housing transactions from January 2010 (when the CSO data began).

We were provided with OPW flood maps for Cork city and these were geocoded to provide information on the flood risk that an area faces. The risk of flooding was identified at the SA level. We captured two types of flood risk: fluvial and tidal. For fluvial flooding, risk was associated with a 1 in 10, 1 in 100 and 1 in 1000 year event, corresponding to probabilities of flooding of 0.1, 0.01 and 0.001, respectively. For coastal flooding, the associated risk categories were 1 in 10, 1 in 200 and 1 in 1000, corresponding to probabilities of flooding of 0.1, 0.005 and 0.001, respectively. In terms of impact, Figure 2.3 presents a series of plots of the risk of flooding by area for each type of flooding and also the associated probability.

We estimated the effect of these risk categories on house prices for the full sample and then by year, to assess whether the memory of the 2009 flood in Cork had an immediate impact on dwelling prices but dissipated as time progressed.

A brief summary of our results is as follows. Regarding flood risk in 2010, dwellings in SAs that were at risk of fluvial flooding, at all risk levels, were found to have lower prices than dwellings outside flood risk zones. However, post 2010, the significant negative effect disappears, perhaps implying a degree of amnesia with regard to the risk of flooding. Immediately following the 2009 floods, house prices seem to have included a flood risk discount; however, the memory of the 2009 flood impact appears to have faded over time and no negative impact is observed in the years from 2011 onwards. Indeed, in 2016 and 2017 there appears to be a significant positive effect on house prices in flood risk zones. This is likely not to be attributable to the risk itself but to the restricted supply of housing.

The results indicate that there is little evidence to support the hypothesis that house prices are

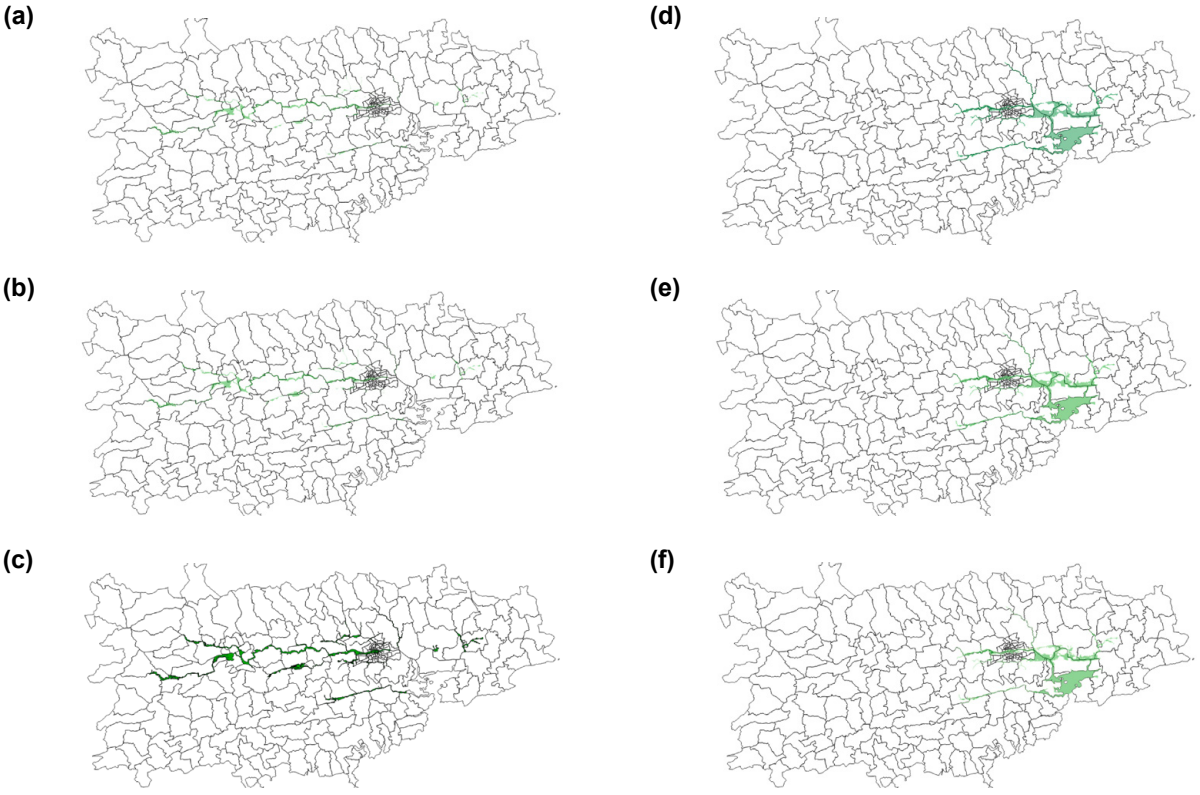

Figure 2.3. Flood risk, by type and annual exceedence probability, for the Lee catchment. (a) Fluvial flooding 0.1 (1 in 10 years); (b) fluvial flooding 0.01 (1 in 100 years); (c) fluvial flooding 0.001 (1 in 1000 years); (d) coastal flooding 0.1 (1 in 10 years); (e) coastal flooding 0.005 (1 in 200 years); and (f) coastal flooding 0.001 (1 in 1000 years).

discounted to account for flood risk in the Cork case. The evidence suggests that there may be some discounting when there has been a very recent flood event, with discounted prices being observed in fluvial flood zones in 2010 immediately following the 2009 floods in Cork. However, this quickly dissipates and by 2011 no negative impact on house prices is observed.

In terms of future research it would be beneficial to expand the sample considered here to include more rural regions as well as a city region. This would enable a distinction to be made between the level of house price discounting in rural areas, where there may be less of a demand, and the level of discounting in a city region, where there may be increased demand and restricted supply. In addition, it would be beneficial, should precise location data become available, to use the exact co-ordinates of the houses sold to pinpoint whether or not they are located within a flood risk zone. At the moment, this analysis is not possible because of limitations on data availability from the CSO because of confidentially concerns.

2.4 Fit for the Future? The Reform of Flood Insurance in Ireland: Resolving the Data Controversy and Supporting Climate Change Adaptation

The previous sections presented new evidence for Ireland on the costs of transport disruptions as a result of extreme weather events and on the effect of flood risk on property prices. These costs, both direct and indirect, may be mitigated by insurance. This section focuses on the key role that flood insurance plays as a coping mechanism for the risk and cost of extreme weather events. In particular, it discusses emerging tensions between the demand for insurance by homeowners and businesses, and the concerns of insurance providers and the national government. We find that appropriate risk assessments and access to flood risk data are currently key bottlenecks for the accessibility and affordability of flood insurance in Ireland.

The Irish National Climate Change Adaptation Framework (DECLG, 2012) and the updated National Adaption Framework (DCCAE, 2018) highlight the importance of insurance mechanisms as a means of tackling climate change, noting both that the insurance industry is a climate-sensitive sector and that it can play a crucial role in capacity building through disseminating information on risk reduction and sending pricing signals (DECLG, 2012). However, it is exactly this function of attaching a price tag to flood risk that causes controversies. There is a degree of distrust from both consumers and the government about how insurers use flood risk information, mixed with concerns that the premiums associated with insuring flood risks may exceed the consumer's ability or willingness to pay.

The evidence of direct and indirect costs outlined previously highlights the negative impacts of flood events on individuals (through their impact on commuting costs and house prices) and businesses. There is increasing reluctance among insurers to cover the costs of these events and increasing pressure on government to act to prevent flooding as a result of these events.

In this context, our research on the insurance industry originates from the question of whether or not current structures and dynamics in the insurance market for flooding cover are fit for the future. From stakeholder engagement and secondary data collection, we propose that current structures and dynamics will need to improve in order to provide accessible and affordable insurance while also minimising moral hazard and, in turn, promoting adaptation. Key areas identified are risk assessment methodologies and the issue of risk data availability, for which we propose potential solutions. Our research highlights the complexity of expectations of different stakeholders. In our view, these would need to be considered in future policy in order to gain support from these groups to legitimise proposed adaptation efforts.

Efforts to reform flood insurance tend to focus on current needs and demands and are often triggered by political pressure to alleviate concerns about rising insurance prices. However, the current emphasis in addressing the emerging problems with the insurance industry, focusing only on the symptoms, can lead to a stop-gap mentality, offering temporary financial relief to homeowners and businesses rather than reforming the system in a forward-looking way. This has been seen with the UK's Flood Re, which has failed to incentivise homeowners and government to reduce risk (Surminski, 2017). Conversely, insurance companies may continue to be deterred from offering affordable flood insurance if risk levels are not managed

effectively. Addressing insurance availability and affordability, therefore, should focus on the interactions between how insurance firms assess risk and what actions government and insurance customers can take to reduce risks and secure lower risk premiums.

This research project undertook a stocktake to clarify the current situation, identifying existing data and highlighting different positions. This is based on a framework of five parameters, developed by Kunreuther and Kousky for disaster insurance in the USA (Kousky, 2017, and applied in Surminski, 2017), that applies a mix of quantitative and qualitative metrics and criteria, based on analysis of the available data, stakeholder interviews and the literature. The stocktake and discussions with stakeholders indicate that access to and use of data are key issues that need to be resolved in order to address short-term, as well as longer term, concerns about flood risk and how it is managed.

Recent advances in public flood risk assessment, which include climate change projections, such as the CFRAM models, are widely praised for being of high quality. However, the impact remains unclear as there is no information available about how the data are taken into account when making public and private decisions, such as insurance underwriting, local planning (including in complying with the Planning System and Flood Risk Management Guidelines), infrastructure investment, property development and house purchases. The one exception to this is the decision-making process around proposed flood relief schemes, as discussed in detail in our paper on urban-level decision making (McDermott and Surminski, 2018). This underlines the importance of developing a new approach to sharing and using flood risk data.

Furthermore, as our discussion emphasises, efforts at reform need to take account of the *underlying causes* of problems in the flood insurance market, that is, rising risk because of both increasing hazard (associated with the effects of climate change) and changes in exposure, as a result of socio-economic trends, as well as address the current symptoms in the form of problems with access to and affordability of flood insurance in Ireland. Current discussion and controversies provide an opportunity for progress on these points

There is an important opportunity in Ireland to develop a truly forward-looking approach to using flood risk data, including for insurance purposes, that enhances climate change adaptation. The current discussions about the Flood Insurance Bill, the latest National Adaptation Framework and efforts to develop an online data portal for flood risk information by the OPW together provide a chance to explore the possibility of a radical shift away from the current approach to flood risk data, a shift that would embed flood insurance aspects into a wider flood risk data platform.

Problems with flood insurance are a symptom of the underlying issue: that flood risk is increasing as a result of climate change and socio-economic trends, such as land use and property development (as demonstrated elsewhere in this project). The only truly sustainable response, therefore, is a significant increase in efforts to address the underlying risks now and in the future, as this will help to ensure the affordability and availability of insurance. The benefits of such action would also reach far beyond insurance as they would address the wider negative impacts that flooding has, such as emotional stress, health issues and declines in economic competitiveness of impacted communities and regions.

2.5 How Normative Interpretations of Climate Risk Assessment Affect Local Decision Making – An Exploratory Study at the City Scale in Cork, Ireland

Urban areas already suffer substantial losses in both economic and human terms from climate-related disasters. These losses are anticipated to grow substantially in the coming decades, in part as a result of the impacts of climate change. It has been estimated that 40 million people and US$3 trillion in assets are already vulnerable to coastal flooding in cities around the world (Nicholls *et al*., 2007). Under even modest SLR (0.5 m), by 2070 these numbers could rise to 150 million people and US$35 trillion. Urban decision makers face the challenge of deciding how to respond to this risk among all of the other pressures that urban areas face: cities are subject to a complex interplay of economic growth, population trends, land use and social processes, which all influence and are influenced by climate risk. Addressing this requires collaborative management across spatial, political and organisational boundaries involving a broad range of stakeholders, who take

decisions that determine current and future risks – for example where to locate new housing developments, how to design new flood barriers, what materials to use for new roads and how to ensure a functioning water and power supply (Surminski and Leck, 2017).

Planning decisions have a potentially large effect on exposure to future flood risk. For example, projections of future flood losses in Europe indicate a possible sixfold increase in losses (from €4 billion per year to €24 billion per year by 2050); roughly two-thirds of that projected increase is accounted for by changes in exposure, with one-third accounted for by the expected increase in flood hazard as a result of climate change (Jongman *et al*., 2014). Planning decisions taken today also have the potential to lock in exposure for decades to come, thus making these decisions particularly sensitive to the uncertainty surrounding future risks associated with climate change. For example, observing rapid recovery following large-scale urban flooding, Kocornik-Mina *et al*. (2015, p. 4) note that "flooding poses an important challenge for urban planning because adaptation away from flood-prone locations cannot be taken for granted even in the aftermath of large and devastating floods". For cities vulnerable to flood risk, these issues represent pressing and critical dilemmas in terms of how to balance the desire for urban expansion – particularly the development of dense urban cores – against the requirement to manage and limit flood risk. Avoiding rising flood losses needs to be balanced with the development requirements of urban areas, in terms of both population and infrastructure, prompting calls for investment in low-carbon, climate-resilient infrastructure (OECD, 2014a).

In this study we investigated the process of translating climate risk data into action at the city level. We applied a commonly used decision framework as our backdrop and explored where in this process climate risk assessment and normative political judgements intersect. We used the case of flood risk management in Cork city in Ireland to investigate what is needed for translating risk assessment into action at the local city level.

Cork is a particularly interesting case as it is very advanced in its climate and flood risk assessment and management approach, with sophisticated risk analytics and high-risk awareness, as well as extensive participatory structures and approved budgets for flood protection. However, despite more accurate data and an increasing range of theoretical approaches that city planners can call on to assist with using these data, there are some fundamental challenges that appear to hamper the translation of risk assessment into action. Identifying and embracing these challenges up front could strengthen the urban adaptation process – this may, in fact, turn out to be the biggest advantage of climate risk assessment: it offers an opportunity to create a shared understanding of the problem and enables an informed evaluation and discussion of remedial action. If used wisely this "pulling power" of data can bring together those who make decisions, as proposed by Surminski (2017).

Although the quality and relevance of the climate risk assessment are clearly important, it is the interpretation and application in the decision-making process that determines if and what action is taken. Ignoring or wrongly interpreting risk data when making urban decisions can lead to maladaptation, such as creating unnecessary costs today through the adoption of inefficient defensive measures and poorly thought-out development restrictions. In turn, this can result in higher future costs.

This underlines the important role that those tasked with compiling risk assessments need to play with regard to the interpretation of their risk assessments, as described by Krebs (2011, p. 4850): "the role of scientists is to help policy-makers understand how far scientific understanding has evolved in this landscape, and, if there are competing hillocks, to explain why in the clearest possible terms". While achieving an improved "understanding" of the data is clearly an important aspect, it is the question of "translating" risk assessments into policy that appears to be the biggest challenge for evidence-based decision making, requiring political judgement by "weaving together scientific evidence, economics and public acceptability of risk" (Krebs, 2011, p. 4845).

Throughout any decision-making process, there are points when objective risk data meet subjective prioritisation and normative judgements and, potentially, controversy. Typical examples are the appetite for risk and an understanding of what risk levels may be deemed acceptable, the choice of type and location of flood defences, and how to balance current development pressure with increasing risk exposure.

The evidence presented is based on focus group discussions at two stakeholder workshops and a series of individual meetings and telephone discussions with stakeholders involved in local decision making related to flood risk management and adaptation to climate change, both nationally in Ireland and at the local level in Cork city. Respondents were chosen on the basis of their expertise and/or involvement in decision-making processes locally and nationally. Representatives of groups affected by flood risk and flood risk management/adaptation efforts were also included.

The Cork example highlights that, despite ever-more accurate data and an increasing range of theoretical approaches available to local decision makers, it is the normative interpretation of this information that determines what action is taken. The use of risk assessments for decision making is a process that requires normative decisions, such as setting "acceptable risk levels" and identifying "adequate" protection levels, which will not succeed without broader buy-in and stakeholder participation. Identifying and embracing these up front could strengthen the urban adaptation process – this may, in fact, turn out to be the biggest advantage of climate risk assessment: it offers an opportunity to create a shared understanding of the problem and enables an informed evaluation and discussion of remedial action.

The decision-making process for adaptation at the urban governance level requires substantial normative decision making, both prior to and in response to climate risk assessment. A standard depiction from the decision theory literature (e.g. Willows *et al*., 2003) frames the pathway to taking action as a "decision cycle" (sometimes called the "policy cycle") (Figure 2.4).

The risk assessment stage is typically held out as a focal point across the entire decision-making cycle. It is taken as the objective point of departure for normative decision making and introduces key information, often in the form of a menu of scenarios and adaptation measures (Surminski and Leck, 2017). Yet, the assessment itself is framed by subjective decisions and a host of underlying assumptions. On delivery of a strategic evaluation of climate risk assessment, decision makers must form subjective judgements and take appropriate action. A growing body of work in the risk management literature has emphasised the difficulties in transitioning from expert (or objective) evaluation to normative (or value-based) decision making.

A risk assessment can provide the necessary evidence and assist those tasked with making these relevant decisions, but it also needs local buy-in. In the case of Cork, we note a general willingness to engage with and consult risk, because the flood risk challenge

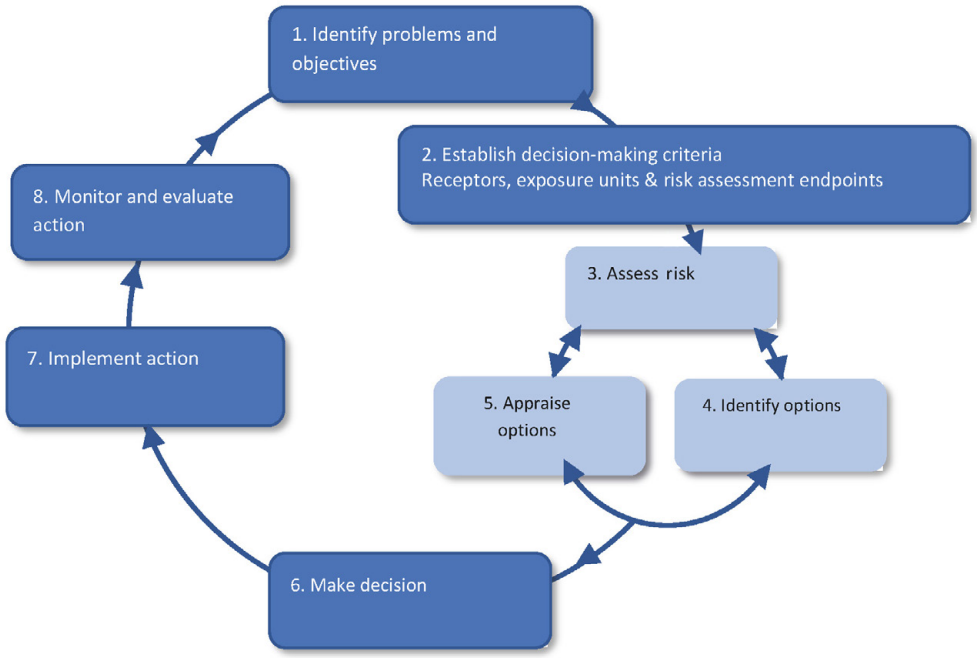

Figure 2.4. Different stages of the "decision cycle".

is so evident and flooding in the city is a regular occurrence. However, even then there are conflicting priorities, as seen with urban planning decisions. Given this challenge, any notion of uncertainty or lack of evidence around the consequences of climate change and impacts on flooding can negatively impact the buy-in of urban planners (see, for example, Carter *et al*., 2015), as well as the general public (as noted in our stakeholder discussions). Uncertainty in relation to the effects of climate change on future risk need not be a barrier to action; there are now more and more examples of how to make decisions under uncertainty, as well as a growing number of examples of climate risk assessments in cities where uncertainty has not been treated as a barrier to urban adaptation. However, the presence of uncertainty must be acknowledged openly and its relevance to the decision at hand assessed and communicated clearly, both to end-users (decision makers) and to the broader public, so that uncertainty does not become a "grenade" in local debates, used to undermine any proposed interventions.

Equally important is transparency and clarity on data limitations as a means of defusing controversy and tension over identifying risks and the selection of risk management options. Otherwise, risk assessments and risk data provision can turn into political discussions.

These last two points – on uncertainty and limitations of data – represent important future challenges for researchers (and practitioners) engaged in climate risk assessment, to enable meaningful ways to be found of communicating to non-specialists how risks are anticipated to evolve in future – both as a result of climate change and as a result of other risk drivers including socio-economic factors – without shying away from a frank presentation of the uncertainties and limitations inherent in any such forecasts (Krebs, 2011). An important component of responding to this challenge will probably require a greater degree of interaction between the data scientists and the end-users.

This underlines the importance of the participation of end-users in the whole process, from data generation and risk assessment to decision making. Generally speaking, most climate change risk assessments conducted at the city level have placed significant emphasis on the participation of a broad range of stakeholders. Encouragingly, this point has gained prominence in Ireland and is increasingly embedded in policy documents and official guidelines (e.g. the latest version of the National Adaptation Framework, local authority guidelines and the Climate Ireland platform), which now promote a participative approach to adaptation planning.

Importantly, the challenges that we have identified are not insurmountable; embracing these challenges up front, fostering greater participation of stakeholders and decision makers earlier in the process, the co-creation of data, and generating buy-in from the local community represent potentially powerful responses. These types of initiatives will not be without costs (in terms of both time and resources), but may help to avoid or reduce the kind of controversies we have observed in the Cork case study, which risk derailing the decision-making process and delaying adaptation actions at the implementation stage.

Finally, an important, but often overlooked, aspect is the need for narratives to bridge the gap between risk assessment and normative decisions: risk management tends to come with a negative connotation. In Cork, for example, we noted that a local business association did not make a single reference to flooding, nor to climate change, in its recent submission on government planning policy, *Cork 2040: Our Vision* (Cork Chamber, 2017), giving the impression that flood risk management, and adaptation to climate change more generally, have no place in the articulation of a city's future aspirations. Challenging this mindset is an important task in responding to the risks of climate change. During our stakeholder discussions, the value in presenting a more positive narrative around flood risk management was acknowledged; the ambition of achieving climate resilience might be seen as a sign of city strength and community cohesiveness. Creating that kind of shared vision of a climate-resilient future at a local level could be an important first step to generating the buy-in and engagement that appear crucial to navigating the challenges that we have identified in moving from risk assessment to action in an urban context.

In conclusion, we find that the translation of risk assessments into local action should be seen as a process that requires buy-in and development from within the local decision-making body, as well as support from others, for example through data and

expertise. Recent efforts in Ireland, for example through Climate Ireland, to support greater openness and the provision of data, decision-making tools and advice to support adaptation planning are promising, but all involved need to recognise that providing data and tools is not necessarily sufficient and more emphasis needs to be put on creating an ongoing process of engagement, involvement and participation to navigate the difficult normative decisions that local decision makers face.

References

Atreya, A., Ferreira, S. and Kriesel, W., 2013. Forgetting the flood? An analysis of the flood risk discount over time. *Land Economics* 89: 577–596.

Carter, J., Cavan, G., Connelly, A., Guy, S., Handley J. and Kazmierczak, A., 2015. Climate change and the city: building capacity for urban adaptation. *Progress in Planning* 95: 1–66.

Changnon, S.A., Pielke, R. A. Jr, Changnon, D., Sylves, R.T. and Pulwarty, R., 2000. Human factors explain the increased losses from weather and climate extremes. *Bulletin of the American Meteorological Society* 81: 437–442.

Cohen, J.P., Cromley, R.G. and Banach, K.T., 2015. Are homes near water bodies and wetlands worth more or less? An analysis of housing prices in one Connecticut town. *Growth and Change* 46: 114–132.

Coll, J., Bourke, D., Skeffington S.M. and Gormally, M., 2014. Projected loss of active blanket bogs in Ireland. *Climate Research* 59: 103–115.

Cork Chamber, 2017. *Ireland's National Planning Framework Submission by Cork Chamber*, *March 2017.* Cork Chamber, Cork, Ireland.

CSO (Central Statistics Office), 2016a. *Census 2016 Results Profile 2 – Population Distribution and Movements*. CSO, Dublin.

CSO (Central Statistics Office), 2016b. *RPPI Technical Paper. Launch of New Residential Property Price Index (RPPI)*. Available online: http://www.cso.ie/en/media/csoie/newsevents/presentations/RPPItechnical.pdf (accessed 21 February 2018).

Davis, D.R. and Weinstein, D.E., 2002. Bones, bombs, and break points: the geography of economic activity. *American Economic Review* 92: 1269.

DCCAE (Department of Communications, Climate Action and Environment), 2017. *National Mitigation Plan*. DCCAE, Dublin.

DCCAE (Department of Communications, Climate Action and Environment), 2018. *National Adaptation Framework – Planning for a Climate Resilient Ireland*. DCCAE, Dublin.

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

DEFRA (Department for Environment, Food and Rural Affairs), 2012. *UK Climate Change Risk Assessment: Government Report 2012*. DEFRA, London.

DEHLG (Department of the Environment, Housing and Local Government), 2007. *Ireland – National Climate Change Strategy 2007–2012*. DEHLG, Dublin.

Desmond, M., O'Brien, P. and McGovern, F., 2017. *A Summary of the State of Knowledge on Climate Change Impacts for Ireland*. Environmental Protection Agency, Johnstown Castle, Ireland.

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

DHPLG (Department of Housing, Planning and Local Government), 2018. *Project Ireland 2040: National Planning Framework.* DHPLG, Dublin.

EC (European Commission), 2009. *White Paper – Adapting to Climate Change: Towards a European Framework for Action.* COM(2009) 147/4. European Commission, Brussels.

EC (European Commission), 2013. EU Adaptation Strategy. Available online: https://ec.europa.eu/clima/policies/adaptation/what_en#tab-0-0 (accessed May 2019).

Eves, C. and Wilkinson, S., 2014. Assessing the immediate and short-term impact of flooding on residential property participant behaviour. *Natural Hazards* 71: 1519–1536.

Ford, A., Jenkins, K., Dawson, R., Pregnolato, M., Barr, S. and Hall, J., 2015. Simulating impacts of extreme weather events on urban transport infrastructure in the UK. In Dolan, T. and Collins, B. (eds), *International Symposium for Next Generation Infrastructure Conference Proceedings*, 30 September–1 October 2014, International Institute of Applied Systems Analysis (IIASA), Schloss Laxenburg, Vienna, Austria. University College London Department of Science, Technology, Engineering and Public Policy, London, pp. 233–238.

Gleeson, E., McGrath, R. and Treanor, M., 2013. *Ireland's Climate: The Road Ahead*. Met Éireann, Dublin.

Guha-Sapir, D., Vos, F., Below, R. and Ponserre, S., 2010. *Annual Disaster Statistical Review: The Numbers and Trends.* Centre for Research on the Epidemiology of Disasters (CRED), Universite Catholique de Louvain, Brussels.

Halcrow, 2014. *Lee Catchment Flood Risk Assessment and Management Study: Final Report*. Halcrow, Dublin.

Hammond, M.J.J., Chen, S.S., Djordjević, S., Butler, D. and Mark, O., 2013. Urban flood impact assessment: a state-of-the-art review. *Urban Water Journal* 12: 1–16.

IFPCG (Interdepartmental Flood Policy Co-ordination Group), 2016. *Interim Report to Government*. Available online: https://www.opw.ie/en/media/Interim-Report-Interdepartmental-Flood-Policy-Coordination-Group-final.pdf (accessed 10 May 2019).

IPCC (Intergovernmental Panel on Climate Change), 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. IPCC, Geneva.

IPCC (Intergovernmental Panel on Climate Change), 2013. *Climate Change 2013: The Physical Science Basis. Summary for Policymakers*. IPCC, Switzerland.

Jongman, B., Hochrainer-Stigler, S., Feyen, L., Aerts, J.C., Mechler, R., Botzen, W.W., Bouwer, L.M., Pflug, G., Rojas, R. and Ward, P.J., 2014. Increasing stress on disaster-risk finance due to large floods. *Nature Climate Change* 4: 264–268.

Kocornik-Mina, A., Michaels, G., McDermott T. and Rauch, F., 2015. *Flooded Cities*. CEP Discussion Paper No. 1398. Centre for Economic Performance, London School of Economics, London.

Kousky, C., 2017. *Financing Flood Losses: A Discussion of the National Flood Insurance Program*. RFF Discussion Paper 17-04. Resources for the Future, Washington DC.

Krebs, J.R., 2011. Risk, uncertainty and regulation. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 369: 4842–4852.

Lehane, M. and O'Leary, B., 2012. *Ireland's Environment – An Assessment.* Environmental Protection Agency, Johnstown Castle, Ireland.

Lowe, J.A., Howard, T., Pardaens, A., Tinker, J., Jenkins, G., Ridley, J., Leake, J., Holt, J., Wakelin, S., Wolf, J., Horsburgh, K., Reeder, T., Milne, G., Bradley, S. and Dye, S., 2009. *UK Climate Projections Science Report: Marine and Coastal Projections*. Met Office Hadley Centre, Exeter, UK.

McDermott, T.K.J., 2016. *Investing in Disaster Risk Management in an Uncertain Climate*. World Bank Policy Research Working Paper WPS7631. World Bank, Washington DC.

McDermott, T. and Surminski, S., 2018. How normative interpretations of climate risk assessment affect local decision making – an exploratory study at the city scale in Cork, Ireland. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 376(2121).

MacDonald, D.N., Murdoch, J.C. and White, H.L., 1987. Uncertain hazards, insurance, and consumer choice: evidence from housing markets. *Land Economics* 63: 361–371.

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

Mendelsohn, R., 2012. The economics of adaptation to climate change in developing countries. *Climate Change Economics* 3: 125006.

Met Éireann, 2016. *Weather Summary Winter 2016*. Met Éireann, Dublin.

Michaels, G. and Rauch, F., 2018. Resetting the urban network: 117–2012. *Economic Journal* 128: 378-412.

Miguel, E. and Roland, G., 2011. The long-run impact of bombing Vietnam. *Journal of Development Economics* 96: 1–15.

Morrissey, K., O'Donoghue, C., Clarke, G. and Li, J., 2013. Using simulated data to examine the determinants of acute hospital demand at the small area level. *Geographical Analysis* 45: 49–76.

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

National Directorate For Fire And Emergency Management, 2016. *Report on Flooding December 4 2015 – January 13 2016*. Department of Housing, Planning, Community and Local Government, Dublin.

NDFEM (National Directorate for Fire and Emergency Management), 2014. *Report on Severe Weather from 13 December 2013 to 17 February 2014*. Department of the Environment, Community and Local Government, Dublin.

Nicholls, R.J., Hanson S., Herweijer C., Patmore N, Hallegatte S., Corfee-Morlot J., Chateau J. and Muir-Wood R., 2007. *Ranking of the World's Cities Most Exposed to Coastal Flooding Today and in the Future*. OECD Environment Working Paper No. 1. Organisation for Economic Co-operation and Development, Paris.

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

Nolan P., Goodman, P., O'Sullivan, J., Sweeney, C., Gleeson, E. and McGrath, R., 2013. Climate change: impacts on Irish temperatures. In Gleeson, E., McGrath, R. and Treanor, M. (eds), *Ireland's Climate: The Road Ahead*. Met Éireann, Dublin, pp. 17–19.

O'Donoghue, C., Ballas, D., Clarke, G., Hynes, S. and Morrissey, K., 2012. *Spatial Microsimulation for Rural Policy Analysis*. Springer Nature, Basel, Switzerland.

OECD (Organisation for Economic Co-operation and Development), 2014a. *Cities and Climate Change: National Governments Enabling Local Action*. OECD, Paris.

OECD (Organisation for Economic Co-operation and Development), 2014b. *Seine Basin, Île-de-France, 2014: Resilience to Major Floods*. OECD, Paris.

OPW (Office of Public Works) and Department of the Environment, Heritage and Local Government (DEHLG), 2009. *The Planning System and Flood Risk Management*. The Stationery Office, Dublin.

Oreskes, N., Stainforth, D.A. and Smith, L.A., 2010. Adaptation to global warming: do climate models tell us what we need to know? *Philosophy of Science* 77: 1012–1028.

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

Pielke R.A. Jr, Gratz, J., Landsea, C.W., Collins, D., Saunders, M.A. and Musulin, R., 2008. Normalized hurricane damage in the United States: 1900–2005. *Natural Hazards Review* 9: 29–42.

Pryce, G., Chen, Y. and Mackay, D., 2009. Flood risk, climate change, housing economics, and the four fallacies of extrapolation. *Housing Economics* 2007: 1–33.

Ran, J. and Nedovic-Budic, Z., 2016. Integrating spatial planning and flood risk management: a new conceptual framework for the spatially integrated policy infrastructure. *Computers, Environment and Urban Systems* 57: 68–79.

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

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

Surminski, S., 2017. *Fit for Purpose and Fit for the Future? An Evaluation of the UK's New Flood Reinsurance Pool*. RFF Discussion Paper 17-04. Resources for the Future, Washington DC.

Surminski, S. and Leck, H., 2017. From agenda-setting to implementation: the role of multisectoral partnerships in addressing urban climate risks. *Earth's Future* 5: 966–978.

Tanner, T. and Rentschler, J., 2015. *Unlocking the "Triple Dividend" of Resilience – Why Investing in DRM Pays Off*. Overseas Development Institute, London.

Turnbull, G., Zahirovic-Herbert, V. and Mothorpe, C., 2013. Flooding and liquidity of the Bayou: the capitalization of flood risk into house value and ease-of-sale. *Real Estate Economics* 41: 103–129.

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

Vega, A., Kilgarriff, P., O'Donoghue, C. and Morrissey, K., 2017. The spatial impact of commuting on income: a spatial microsimulation approach. *Applied Spatial Analysis and Policy* 10: 475–495.

Willows, R., Reynard, N., Meadowcroft, I. and Connell, R. 2003. *Climate Adaptation: Risk, Uncertainty and Decision-making. UKCIP Technical Report*. UK Climate Impacts Programme, Oxford.

Zhang, L., 2016. Flood hazards impact on neighborhood house prices: a spatial quantile regression analysis. *Regional Science and Urban Economics* 60: 12–19.

Abbreviations

AEP	Annual exceedance probability
BER	Building Energy Rating
CFRAM	Catchment Flood Risk Assessment Management
CSO	Central Statistics Office
ED	Electoral division
EPA	Environmental Protection Agency
EU	European Union
HP	Haase–Pratschke
OPW	Office of Public Works
RPPI	Residential Property Price Index
SA	Small area
SAPS	Small-area population statistics
SLR	Sea level rise
SMILE	Simulated Model of the Irish Local Economy
UCC	University College Cork
WP	Work package

Appendix 1 List of Project Outputs and Dissemination Activities

A1.1 Research and Policy Papers

1. McDermott, T. and Surminski, S., 2018. How normative interpretations of climate risk assessment affect local decision making – an exploratory study at the city scale in Cork, Ireland. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 376(2121).
2. Surminski, S., 2017. *Fit for the Future? The Reform of Flood Insurance in Ireland: Resolving the Data Controversy and Supporting Climate Change Adaptation*. GRI Policy Paper. Available online: http://www.lse.ac.uk/GranthamInstitute/publication/fit-for-the-future-the-reform-of-flood-insurance-in-ireland-resolving-the-data-controversy-and-supporting-climate-adaptation/ (accessed May 2019). Note: this policy report was designed and printed by the LSE partners and physical copies of the report were handed out to stakeholders at our workshop in Cork and at other engagement activities.
3. Surminski, S., 2017. Flood insurance and flood risk reduction. In *Oxford Research Encyclopedia of Natural Hazard Science*. Oxford Research Encyclopedias. Oxford University Press, Oxford.
4. Kilgarriff, P., McDermott, T.K.J., Vega, A., Morrissey, K. and O'Donoghue C., 2018. The impact of flooding disruption on the spatial distribution of commuter's income. *Journal of Environmental Economics and Policy* 8: 48–64. Note: a summary of preliminary research findings from this paper was published as a blog post on the popular and influential IrishEconomy.ie blog in December 2016: http://www.irisheconomy.ie/index.php/2016/12/12/counting-the-cost-of-last-winters-flooding-evidence-from-disruptions-to-the-road-network/ (accessed May 2019).
5. McDermott, T.K.J., 2018. *Translating Flood Risk Assessment into Local Urban Action*. Whitaker Institute Policy Brief No. 39, July 2018. NUI Galway, Ireland. Available online: http://whitakerinstitute.ie/wp-content/uploads/2018/07/Whitaker_Policy-Brief_no.-39_Tom-McDermott.pdf (accessed May 2019).

A1.2 Dissemination Activities, Outreach and Stakeholder Engagement

(in approximately chronological order)

1. Stakeholder workshop in Dublin (EPA offices) in June 2016 (and workshop summary note circulated to participants after the event).
2. Bilateral meetings with Cork City Council on 29 June 2016.
3. Research findings presented by Paul Kilgarriff at the Regional Science Association's Student and Early Career Conference at Newcastle Business School (UK) on 28 October 2016.
4. Tom McDermott invited to present to the Climate Change Advisory Council's Adaptation Committee in January 2017 (unable to attend but submitted a seven-page discussion document of key points related to "Costing climate impacts and adaptation for Ireland", the themes of the ARC research project).
5. Webinar on insurance and adaptation in Ireland in February 2017.
6. Several bilateral telephone conversations with the National Flood Forum, insurance companies and the risk modelling firm RMS following the insurance webinar in February/March 2017.
7. Tom McDermott invited to present to the Sectoral Adaptation Committee on 29 March 2017 on the interim research findings from the ARC project.
8. Workshop in Cork (Environmental Research Institute, UCC) in May 2017. Pre-workshop discussion note circulated to registered

participants in advance of the workshop; presentations at the workshop by project team members; and workshop summary note circulated to participants after the event.

9. Invited lecture by Swenja Surminski to the Society of Actuaries, Dublin, on 8 May 2017.
10. Bilateral meetings in Dublin with the OPW and Insurance Ireland on 8 May 2017.
11. Invited public lecture by Swenja Surminski at the Environmental Research Institute, UCC on 9 May 2017.
12. Swenja Surminski was invited to give a presentation about the project at the European Commission adaptation and insurance conference in Brussels on 30 June 2017. This triggered interest in the situation in Ireland from international insurers and the European Commission, which is investigating the data platform idea for other countries.
13. In October 2017, Swenja Surminski was invited by the Joint Committee on Finance, Public Expenditure and Reform and the Taoiseach to give oral evidence to the Scrutiny of the Flood Insurance Bill 2016. The formal invitation references the ARC research project explicitly (for a copy of the invitation letter see section A1.4).
14. Tom McDermott was invited to contribute background material on the economics of climate change impacts and adaptation for Ireland's National Adaptation Framework (published in January 2018).

A1.3 Media Coverage

1. English, E., 2017. Insurers urged to share flood risk data. Available online: https://www.irishexaminer.com/ireland/insurers-urged-to-share-flood-risk-data-449564.html (accessed 12 September 2019).
2. Melia, P., 2017. Homes could be priced out of flood cover. Available online: https://www.independent.ie/business/personal-finance/property-mortgages/homes-could-be-priced-out-of-flood-cover-35694446.html (accessed 12 September 2019).

A1.4 Invitation to Address Oireachtas Committee

An Comhchoiste um Airgeadas, Caiteachas Poiblí agus Athchóiriú, agus an Taoiseach Teach Laighean Baile Átha Cliath 2 Teil: (01) 618 3850/3770 Ríomhphost: fincom@oireachtas.ie		**Joint Committee on Finance, Public Expenditure and Reform, and Taoiseach** Leinster House Dublin 2 Tel: (01) 618 3850/3770 Email: fincom@oireachtas.ie

Issued by email

Ref: I 2017/302

7 November, 2017

Ms. Swenja Surminski
Senior Research Fellow
Grantham Research Institute on Climate Change and the Environment
London School of Economics
Houghton Street
London
WC2A 2AE
United Kingdom

RE: Scrutiny – Flood Insurance Bill 2016 – Deputy Michael McGrath [Private Members Bill]

Dear Ms Surminski

I am directed by the Chairman of the Joint Committee, Deputy John McGuinness TD, to invite you in your capacity as the GRI lead in the *Costing Climate Change Impacts and Adaption in Ireland project* to attend a meeting of the Joint Committee which is scheduled for 11.00 am on **Thursday, 23 November** in Committee Room 2, Leinster House.

The Joint Committee wishes to engage with you on the following topic: *Scrutiny of the Flood Insurance Bill 2016*. Please note that a copy of the Bill, an explanatory memorandum and copy of the Second Stage parliamentary debate is also provided for your information.

Deputy Michael McGrath, Sponsor of the Bill and other stakeholders will also attend the meeting. The format of the meeting is that you will be invited to make a short initial presentation **(maximum 5 minutes)** which will be followed by an open discussion with the members of the Committee. In regard to any presentation, briefing or supplementary information you may have, I am to request that these would be forwarded, in electronic format, to fincom@oireachtas.ie by 4pm on Friday 17 November so as to facilitate the distribution to the members prior to the meeting.

Further, I wish to draw your attention to three matters:

1. The unrevised version of committee debates (transcripts) will appear on the Oireachtas Website normally within a week of the debate taking place. If witnesses wish to suggest minor amendments to their own contributions, they can do so, ensuring they are clearly marked, by emailing committee.debates@oireachtas.ie within one week of publication on the website.

2. All proceedings of the Dáil, including Committees when in public session are broadcast. A playback facility on the Oireachtas website allows proceedings to be viewed after the event. If a video copy of a particular proceeding is required please contact the Broadcast Manager in advance of the meeting.
3. The meeting will be conducted in public session and will be televised within the Leinster House complex. Footage of the meeting will be available to broadcasting organisations and a transcript will be published in due course. The meeting will be web-cast live. Further, RTÉ also receives the feed live and web-casts selected Committee meetings on its website.

Is beartas de chuid Sheirbhís Thithe an Oireachtais é fáilte a chur roimh úsáid na Gaeilge agus éascaíonn an tSeirbhís úsáid na Gaeilge leis an tSeirbhís. Más mian leatsa Gaeilge a úsáid ag cruinniú an Choiste, ná bíodh aon drogall ort é sin a chur in iúl dúinn chun gur féidir linn é a áireamh sna socruithe praiticiúla a bheidh á gcur i gcrích againn le haghaidh an chruinnithe.

It is Houses of the Oireachtas Service policy to welcome the use of the Irish language and the Service facilitates the use of the language with the Service. If you wish to use the Irish language at the Committee meeting, please don't hesitate to let us know so that we can take this into account when making the practical arrangements for the meeting.

If you need any clarification in relation to this correspondence, please do not hesitate to contact me.

Yours sincerely

Bríd Dunne,

Clerk to the Joint Committee

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

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

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

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

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

Ár bhFreagrachtaí

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

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

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

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

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

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

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

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

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

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

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

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

EPA Research Report 301

Adaptive Responses to Climate Impacts (ARC)

Authors: Justin Doran, Thomas McDermott, Paul Kilgarriff, Swenja Surminski and Mauricio Perez Alaniz

Identifying Pressures

Climate change is likely to lead to physical changes in temperature and precipitation and sea level rise, and Ireland is already experiencing the effects of climate change on its weather patterns. These changes bring both risks and opportunities for the Irish economy and for society more broadly. Investment decisions and economic activity will be sensitive to both changes in average conditions and changes in the frequency of extremes. In particular, increasing flood risk has been identified as one of the main threats to Ireland from climate change. Moreover, dealing with flood risk already creates numerous policy challenges, for instance related to insurance, urban planning and flood relief schemes. These challenges are likely to be exacerbated by climate change. Equally important for informing policy is to understand current exposure and vulnerability to these hazards; how these will evolve in response to changing risk profiles and new information about risk; and how policy can influence these processes. These questions are the focus of this report.

Informing Policy

This project identifies several interacting factors that should be considered in designing efficient climate change adaptation strategies. These correspond to questions about how much adaptation should be undertaken, and at what cost, and a related set of questions about who bears the burden of the costs associated with climate change impacts and how exposure to risk is evolving over time and across socioeconomic groups. Particularly urgent from a policy perspective is the need to avoid locking in future vulnerability. Planning decisions made today will likely affect the level of exposure to climate risk for decades to come. However, some adaptation decisions will need to be made now, in spite of the uncertainty around climate impacts. Our research deals directly with these policy issues, related to the process of translating risk assessment into adaptation action at the local level, as well as determining the appropriate role for the private sector, and in particular the role of insurance as a key mechanism to cope with climate risk.

Developing Solutions

Along with new empirical evidence on the costs of flooding and exposure to flood risk, this project also makes policy recommendations in relation to flood insurance and local decision making. We argue that the key to sustainable flood insurance is improved data sharing between the government, insurers and other sectors. The creation of a shared data hub on flood risk would increase transparency and support risk reduction efforts, helping to secure affordable, available and sustainable insurance for the future. Second, in relation to decision making at the local level, our case study of flood risk management in Cork city highlights that, despite ever-more accurate data and a range of decision frameworks, it is normative questions, such as setting “acceptable risk levels” and identifying “adequate” protection levels, that determine what action is taken. Broader buy-in and stakeholder participation as part of climate risk assessments offers an opportunity to create a shared understanding of the problem and an informed evaluation of options for remedial action.

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

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

www.epa.ie

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