Adapting to climate change: Insights on being better prepared for Ireland's future climate

sciendo

Administration, vol. 73, no. 2 (2025), pp. 73–101
doi: 10.2478/admin-2025-0011

Adapting to climate change: Insights on being better prepared for Ireland's future climate

Conor Murphy & Tara Quinn
Irish Climate Analysis and Research UnitS (ICARUS), Department of Geography, Maynooth University, Ireland

Liam Heaphy, Enda O'Brien & Paul Nolan
Irish Centre for High-End Computing (ICHEC), University of Galway, Ireland

Abstract

Climate change is already impacting Ireland, through rising temperatures, more frequent extreme weather events, and increasing risks such as coastal erosion and flooding. Volume 3 of the *Irish Climate Change Assessment Report* (ICCA), launched in 2024, synthesises extensive research on past and projected climate-change impacts and provides a roadmap for being prepared for Ireland's future climate. While climate action nationally has been focused on reducing greenhouse gas emissions, adaptation is an equally pressing concern as climate risks escalate. Drawing on the ICCA, this paper examines how adaptation and resilience are framed in Irish climate policy, and highlights key challenges in implementation. The findings emphasise the need for a systematic, well-resourced, and socially inclusive approach to adaptation. National evaluations indicate slow progress in adaptation, with significant gaps in cross-sectoral coordination, financial investment and community engagement. The authors highlight key opportunities to enhance adaptation efforts, including: setting clear goals and targets; recognising cascading and transboundary risks; integrating people-centred approaches; decision-making under uncertainty; widening the solution space beyond technical interventions; better monitoring and evaluation of adaptation outcomes; and pursuing climate-resilient development. Without substantial improvements in

adaptation planning, Ireland risks unplanned, crisis-driven transformations in response to escalating climate shocks. Strengthening governance, deepening public engagement, and embedding adaptation into all aspects of policy and planning will be critical to achieving a climate-resilient Ireland.

Keywords: Adaptation, climate change, resilience, transformation

Introduction

The Environmental Protection Agency launched the first report on *Ireland's Climate Change Assessment* (ICCA) in 2024. Compiled by twenty-two authors across diverse disciplinary backgrounds and drawing upon >2,500 research and policy publications, the ICCA provides a comprehensive analysis of climate-change science, impacts and policy from an Irish perspective. The ICCA was delivered across four volumes ranging from the assessment of past and projected future climate change (Volume 1: Noone et al., 2024), delivering a climate neutral Ireland (Volume 2: McGookin et al., 2024), being prepared for Ireland's future climate (Volume 3: Murphy et al., 2024a) and realising the benefits of transition and transformation (Volume 4: Moriarty et al., 2024). We draw upon Volume 3 to summarise how adaptation and resilience are framed and operationalised in Irish climate policy. We highlight challenges in implementing adaptation from recent annual reviews of the Climate Change Advisory Council and summarise insights from ICCA Volume 3 on how adaptation can be advanced to better prepare for Ireland's future climate.

The urgency of adaptation

Climate change is happening now. It is not just a concern for future generations. In Ireland, annual average temperatures are now about 1°C higher than in the early twentieth century, and changes in Irish climate are happening in line with global changes (Noone et al., 2024). Murphy et al. (2023) have shown that a human-driven climate-change signal has already emerged in long-term Irish weather records, particularly for annual and seasonal temperature and for heavy rainfall events. The first climate-change attribution study undertaken in Ireland showed how climate change has more than doubled the likelihood of extreme two-day rainfall totals and increased the intensity (by 13 per cent) of the type of heavy rainfall event that gave rise to the flooding in Midleton, Co. Cork, associated with Storm Babet in October 2023 (Clarke et al., 2024). Such extreme events,

together with ongoing sea-level rise and coastal erosion highlight an adaptation deficit nationally and increase the urgency of reducing vulnerability and exposure to ongoing and future changes in climate. This adaptation gap was further exposed in the aftermath of Storm Éowyn in 2025 and the cascading impacts felt across the electricity, communications and water sectors.

Future impacts of climate change will depend on the success of global actions to reduce greenhouse gas emissions. As synthesised in ICCA Volume 1 (Noone et al., 2024);

- Projections of Irish temperature changes consistently show warming, with the magnitude of this warming increasing with delays in global mitigation action. Under 'Early action', the temperature increase averaged across the island of Ireland relative to the recent past (1976–2005) would reach 0.91°C [0.44–1.10°C] by mid-century before falling back to 0.80°C [0.34–1.07°C] at the end of the century. Under 'Late action' to reduce global emissions, by the end of the century, it is projected that the temperature increases could be 2.77°C [2.02–3.49°C] greater than the recent past. Heat extremes will become more frequent and more severe and cold extremes less frequent and less severe with further warming.
- In Ireland, intense precipitation extremes are projected to become more frequent and extreme with further warming in most locations. Projected changes in precipitation accumulations are more uncertain than those for temperature. While winters tend to get wetter and summers tend to get drier, this signal is not consistently found across all global climate models.
- Global mean sea level increases will occur under all scenarios and continue for thousands of years after the global temperature is stabilised. By 2100, projected additional rises range from 0.32–0.6m under 'Early action' to 0.63–1.01m under 'Late action' scenarios, with high uncertainty for the latter case, whereby 2m rise could occur owing to highly uncertain ice sheet processes. Over the next 2,000 years, global mean sea level will rise by about 2 to 3m if warming is limited to 1.5°C, 2 to 6m if limited to 2°C and 19 to 22m with 5°C of warming.

These changes in Irish climate will have impacts significantly greater than those already experienced for all aspects of Irish society, the environment and economy. ICCA Volume 3 reviewed impacts and

adaptation across eight sectors, summarised in Table 1. (Interested readers are encouraged to consult Murphy et al. (2024a) for full details.)

Table 1: Synthesis of key impacts of climate change for sectors assessed in Volume 3 of *Ireland's Climate Change Assessment: Being Prepared for Ireland's Future Climate* (Murphy et al., 2024a)

Ecosystems: Marine, terrestrial and freshwater: Climate change impacts on biodiversity will be felt through changes in growing season length, phenology and species distribution, loss of and damage to ecosystems, and increases in invasive species. In the oceans, changes in ocean temperatures, acidification, salinity and nutrient levels mean that the distributions of some species are likely to shift, with implications not just for ecosystems but also for Irish fisheries. It is vital that all sectors recognise their role in reducing the pressures on biodiversity and protecting ecosystem health.
Coastal environments: With all major cities and many regional towns located close to the coast, Ireland is highly exposed to sea-level rise and coastal erosion, especially in softer sediment coastal zones. Significant increases in sea level beyond 2100 are already inevitable, even under the most optimistic scenarios. Superimposed on the current 100-year flood, mid-range estimates of sea-level rise are projected to quadruple the number of properties affected by flooding in some coastal locations. Coasts are also home to critical infrastructure (e.g. ports) and a rich cultural and natural heritage, and they provide important recreational resources that underpin tourism, all of which are highly exposed to climate change. Yet, there is no clear governance structure for managing climate change in coastal zones.
Agriculture, forestry and land use: Climate change will impact all aspects of Irish agriculture. While increases in productivity can be expected for some crops, decreases can be expected for others. Pests and pathogens are likely to have increased impact on arable and livestock farming, while increases in precipitation amounts and intensity would increase nutrient washout from land with consequent impacts on water quality. The lengthening of the growing season is often given as an example of a positive aspect of climate change for agriculture; however, gains could be offset by extreme events such as longer and more intense droughts increasing crop losses, especially in spring and summer.
Water: In Ireland, climate-change impacts on the hydrological cycle are unfolding in the context of increasing water demands, decreases in water quality and a lack of resilience in water infrastructure. Projected changes in river flows show a wide range; however, increases in extremes of both floods and droughts are expected. Groundwater responses to climate

change are strongly influenced by local settings, with some aquifers likely to see an increase in droughts and others an increase in floods. Increases in water temperature and changes in rainfall patterns and extremes are likely to increase pressures on water quality. Climate change is also likely to increase demand for water resources from households, businesses and agriculture. Impacts on water resources and floods are likely to cascade across other sectors.

Built environment, heritage and rural communities: Ireland's built environment is exposed to flood risks from rivers, the sea and rainfall extremes. Large cities such as Dublin have a higher temperature than the surrounding rural areas due to the urban heat island effect and are thus more exposed to future heat extremes. Increases in extremes present challenges for the integrity of built environments and heritage sites. It is critical that workplaces, hospitals, schools and care homes are resilient to changes in extreme events.

Critical infrastructure: Ireland depends on critical infrastructure for delivering public services, economic growth and a sustainable environment. Transport infrastructure is exposed to increases in sea level and flooding. For energy infrastructure, the key risks are extreme wind speeds, increased precipitation and saturated soils, given their impacts on the electricity distribution network, with flooding also of concern. For information, communications and technology infrastructure, extreme wind speeds and increased storminess are key concerns. Failures in critical infrastructure present a multisector risk.

Health and well-being: Climate-change impacts will directly and indirectly affect health and well-being, while vulnerability is likely to increase as Ireland's population increases and ages over the coming decades. Fewer cold extremes in winter may be positive in terms of reducing excess cold mortality rates, but climate change may also increase existing pressures on the public health service from respiratory diseases such as asthma through increased circulation of aeroallergens in a longer growing season. Without adaptation, increases in extreme rainfall events and floods through their associated impacts on water quality are likely to impact public health. Loss of valued places, flooding and other extremes have consequences for mental health and well-being. Critical health infrastructure, including hospitals and care homes, faces increased risks from heat and flood extremes. Adaptation actions themselves can have unequal health and well-being outcomes for affected populations and should be routinely assessed.

Business, industry and tourism: Ireland, as a small and open economy, is vulnerable to supply chain risks and climate-change impacts and responses that occur in other parts of the world. Local risks to businesses are likely to

arise from changes in extreme events. The scale of climate-change risks for the banking and financial sectors are yet to be quantified, and climate risks are not currently well reflected in insurance, investment and lending. Tourism is highly exposed and vulnerable to climate change. While warmer winters are highlighted as an opportunity for tourism, increased visitor numbers, without careful management, could put at risk sensitive and increasingly exposed and fragile heritage sites, environments and ecosystems.

The links between adaptation and mitigation are also being increasingly recognised. Global mitigation action will determine the scale and feasibility of adaptation. Simply put, the more warming that is experienced, the greater will be the challenges and costs of adaptation. At the same time, even if global efforts at meeting the goals of the Paris Agreement (to maintain global temperature rise to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels) are successful, adaptation to the impacts of climate change will still be necessary (United Nations Framework Convention on Climate Change secretariat, 2016).

However, adaptation planning is not starting from an ideal position. Aside from climate change, the coming decades present major challenges in the areas of energy, health, housing and an ageing population that will further increase vulnerability to climate-change impacts and challenge successful adaptation. Like the climate itself, vulnerability and exposure are not static and will evolve into the future. The adaptation challenge is further complicated by a lack of historical investment in critical infrastructure, a national housing crisis, together with ongoing deterioration in environmental quality, including declines in water quality, biodiversity and ecosystem quality (Murphy et al., 2024a). From a strategic perspective, it is critically important that Ireland scales up its capacity to actively create and maintain a more resilient network of infrastructure and services, including housing. Better custodianship of our natural resources, while anticipating future pressure points will benefit Ireland's adaptation resilience. In contrast, reactive policymaking and token measures can both perpetuate existing weaknesses and create new ones, making climate-induced stress to human and natural systems costlier.

What is adaptation?

The Climate Action and Low Carbon Development Act of 2015 provides a legal definition of adaptation in Irish policy as:

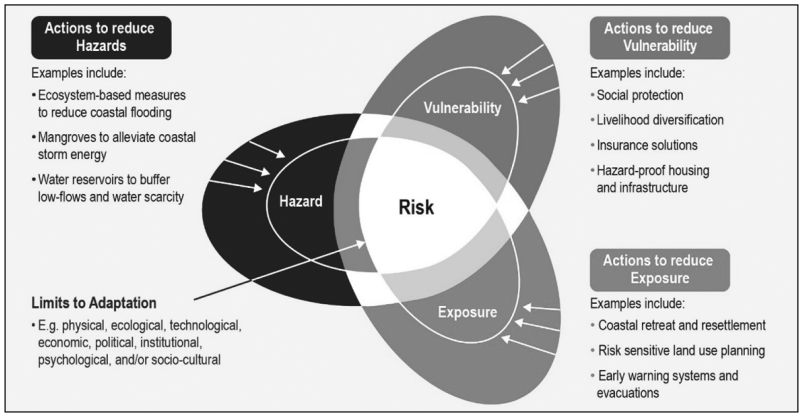
> adjustment to (a) any system designed or operated by human beings, including an economic, agricultural or technological system, or (b) any naturally occurring system, including an ecosystem, that is intended to counteract the effects (whether actual or anticipated) of climatic stimuli, prevent or moderate environmental damage resulting from climate change or confer environmental benefits.

According to the Intergovernmental Panel on Climate Change (IPCC) Working Group II sixth assessment report (IPCC, 2023), adaptation in human systems is the process of adjusting to actual or expected climate and its effects to moderate harm or exploit beneficial opportunities. In natural systems, adaptation involves adjustment to actual climate and its effects, with human intervention potentially facilitating this process. Responsibility for adaptation falls to a range of actors, including governmental, non-governmental, private sector, communities and individuals. In Ireland, adaptation actions have primarily focused on governmental actors; however, achieving a climate-resilient Ireland will require adaptive action from all stakeholders.

Key concepts crucial to understanding and implementing adaptation are risk, exposure and vulnerability (Figure 1). Risk signifies the potential for adverse consequences for human or ecological systems and originates from the dynamic interactions between climate change (changing average conditions and variability), related hazards (e.g. heatwaves, floods, droughts), exposure, and vulnerability. Climate change is not the sole driver of risk; the vulnerability and exposure of societies, infrastructure and ecosystems significantly determine adverse outcomes. Moreover, risk is dynamic and constantly evolving as the frequency and intensity of hazards change and as exposure and vulnerability shift due to various drivers. Adaptation, therefore, should be seen as a process that responds to the dynamics and evolution of risk – a concept known as adaptive risk management. This approach emphasises adaptation as an ongoing process of learning and improvement, involving assessment, action, monitoring and evaluation, learning, and enhancement.

Exposure refers to the presence of people, species or ecosystems, resources, services, infrastructure, or economic, social or cultural assets in places that could be adversely affected by climate hazards. Vulnerability is the propensity to suffer adverse effects when impacted by hazardous events and is intrinsically tied to social, cultural and

Figure 1: Adaptation can reduce risk by addressing one or more of the three risk factors – vulnerability, exposure and/or hazard. The reduction of vulnerability, exposure and/or hazard potential can be achieved through different policy and action choices over time until limits to adaptation might be reached (IPCC, 2019, Figure TS.4)



environmental processes, and can be aggravated by factors such as poverty, gender disparities and lack of social support mechanisms (Coll et al., 2013). For natural systems, a critical component of vulnerability may be the inability to adapt to temporal and spatial impacts and disturbances.

Another common term in adaptation policy is resilience. Resilience is 'the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure' (Ara Begum et al., 2022). Resilience therefore is a positive attribute focused on maintaining capacity for adaptation, learning and transformation. Resilience and adaptation are closely related, with adaptation actions being those that are implemented to realise resilience as an outcome. There is a large body of literature on resilience, parts of which critique the use of the term as a policy objective arguing that it seeks to benefit those in power through maintenance of existing systems and power, and its complexity and challenges in providing purchase for practitioners, among other aspects (e.g. Cutter, 2016; Cote & Nightingale, 2011; Cretney, 2014). It is beyond the scope of this paper to unpack these debates. For our purposes, we highlight that resilience overlaps with concepts of risk and vulnerability; it is about implementing adaptation actions to

create a society, economy and environment that can undergo change and maintain function (i.e. the services and supports that people rely upon), while retaining the capacity to adapt and transform into the future.

Adaptation in Irish climate policy

Adaptation in Irish climate policy sits within a broader global and European landscape. The Paris Agreement and the 2030 Agenda for Sustainable Development (United Nations General Assembly, 2015) establish global goals and strategies for climate action, encompassing both mitigation and adaptation efforts. The Paris Agreement sets a global goal to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change. All parties are encouraged to engage in adaptation by formulating national adaptation plans and periodically updating their priorities, needs, plans and actions. The 2030 Agenda introduces seventeen Sustainable Development Goals (SDGs) to achieve a sustainable future. SDG 13 (Climate action) aligns with the Paris Agreement's objectives, emphasising the importance of strengthening the global response to climate change within the context of sustainable development. Effective climate action (including adaptation) is critical for realising other SDGs due to the interconnectedness of environmental and human development goals.

The European Commission's strategy *Forging a Climate-Resilient Europe* (2021) outlines a vision for the European Union (EU) to become a climate-resilient society by 2050, fully adapted to the unavoidable impacts of climate change. Central to this strategy is reinforcing adaptive capacity and minimising vulnerability in line with the Paris Agreement. The strategy aims to:

1. Improve knowledge and manage uncertainty by advancing adaptation knowledge, enhancing data on climate-related losses, and expanding climate services platforms.
2. Advance adaptation policy development at all governance levels, integrating adaptation into fiscal policy, promoting nature-based approaches and fostering local adaptation actions.
3. Accelerate the implementation of adaptation actions across sectors.
4. Enhance global efforts on adaptation to climate change.

Nationally, the Climate Action and Low Carbon Development Act 2015 and its 2021 Amendment underpin Ireland's policy framework to achieving the national objective of a climate-resilient, biodiversity-rich, environmentally sustainable and climate-neutral economy by 2050. Central to the objective of climate resilience is adaptation, underpinned by the national adaptation framework (NAF). The NAF provides strategic policy focus to ensure adaptation measures are implemented across all government levels. It mandates government departments to develop sectoral adaptation plans for key sectors and requires local authorities to integrate adaptation planning as part of their local authority climate action plans (LACAPs). The NAF defines resilience as:

> the capacity of a system, whether physical, social, or ecological, to absorb and respond to climate change and, by implementing effective adaptation planning and sustainable development (including governance and institutional design), to reduce negative climate impacts while also taking advantage of any positive outcomes. This will allow the system to either return to its previous state or to adapt to a new state as quickly as possible. (Department of Environment, Climate and Communications (DECC), 2018).

Ireland's first statutory five-year NAF (DECC, 2018) identified twelve key sectors needing sectoral adaptation plans. These plans were approved and published in October 2019. They assess climate-change risks for each sector, outline measures to address these risks and ensure sectoral resilience. In 2022, the DECC reviewed the 2018 NAF (DECC, 2022) in line with the requirements of the Climate Act 2021. This review considered feedback from key stakeholders, adoption of the 2021 EU Adaptation Strategy, national policy advances since 2018, and views from the Climate Change Advisory Council (CCAC), other organisations and the public. The key outcome was the recognition of the need for a fundamentally new NAF to account for changing knowledge, legislative environments and lessons learned from the 2018 NAF. The new 2024 NAF (DECC, 2024) has evolved to emphasise justice**,** collaboration and equitable participation in adaptation processes to realise resilience. This is achieved by expanding resilience to encompass dimensions of just resilience, emphasising the fair distribution of adaptation benefits and inclusive decision-making. The 2024 NAF therefore encompasses social,

ecological and economic systems, with a strong emphasis on community-level engagement and marginalised groups. Following publication of the revised NAF in 2024, all local authorities published their LACAPs, aiming to mainstream adaptation into local government systems over the medium and long terms. Local authorities are supported by four climate action regional offices in developing and implementing these plans, an investment that has been critical to building capacity in adaptation at local levels.

Progress in implementing adaptation

Following the publication of the first set of adaptation plans in 2019, the CCAC developed an adaptation scorecard to evaluate progress against the NAF objectives and monitor its implementation (CCAC, 2021, 2022). The adaptation scorecard assesses progress on adaptation based on three primary criteria:

1. *Risk, prioritisation and adaptive capacity*: Evaluates whether sectors are identifying and monitoring risks, addressing key knowledge gaps, and building adaptive capacity.
2. *Resourcing and mainstreaming*: Assesses whether sectors are incorporating climate-change considerations into decision-making and if adaptation is being appropriately mainstreamed and resourced.
3. *Governance, coordination and cross-cutting issues*: Examines whether sectors are ensuring coherence with other policies and if systemic coordination exists both within and across sectors.

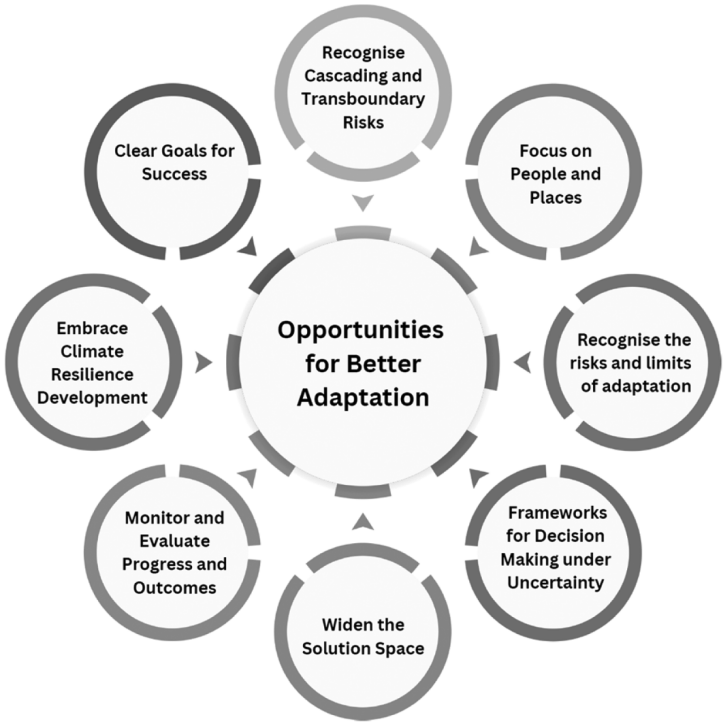
In its 2022 annual review of adaptation, the CCAC (2022) reported that despite significant vulnerabilities and exposure to climate change, most sectors showed only moderate or limited progress towards adaptation. Some sectors demonstrated no progress, and others did not engage sufficiently with the review process to allow evaluation. Only two sectors – flood risk management and local government – exhibited good progress, with no sector achieving advanced progress. The 2023 review (CCAC, 2023), noted improved performance in mainstreaming adaptation into policies and plans, but noted gaps in human and financial resourcing, understanding and integration of vulnerability, and the need for greater policy coherency across national and local plans to avoid ad hoc implementation. In its most recent evaluation (CCAC, 2024), the CCAC noted the persistence of

key gaps in adaptation financing, the development and implementation of adaptation targets and indicators, systemic integration of cross-cutting issues and cascading risks across sectors and levels of government, the need for a national climate damage risk register and better integration of land use and planning into adaptation. So, while progress is being made, significant challenges and barriers persist.

Opportunities for doing better

In considering how adaptation planning might be improved and identifying opportunities for doing so, ICCA Volume 3 highlighted the following areas upon which to focus, informed by available international and national literature (Figure 2).

Figure 2: Opportunities for better adaptation planning and outcomes highlighted by *Ireland's Climate Change Assessment: Volume 3* (Murphy et al., 2024a)



Clear goals for adaptation and resilience

For adaptation to be successful, clear goals need to be established and agreed, progress monitored, outcomes tracked, and lessons acted upon. While the national climate objective establishes the policy goal of a resilient Ireland, there is no agreement on what a climate-resilient Ireland would look like. A simple focus on resilience in each sector could result in conflicts of interest and contestation. Successful adaptation actions should be feasible, effective and align with established principles of justice. In Ireland, as elsewhere, adaptation has predominantly been framed through a technical lens, emphasising quantifiable physical risks in an impacts-led approach. Less consideration has been given to community-level feasibility, the legitimacy of adaptation, its unequal outcomes, or how reducing existing vulnerabilities can serve as a starting point. These gaps need to be addressed to advance research and policy toward a more just climate-resilient Ireland.

Recognise cascading and transboundary risks

Adaptation in Ireland has often taken a sectoral focus, which has its advantages and disadvantages. However, this approach has yet to include critical areas such as coastal environments, Ireland's islands, the built environment, finance, tourism and sport. Each of these areas has significant vulnerabilities and is likely to experience increased climate risks, and thus it is imperative that adaptation planning extends to cover these gaps.

Successful adaptation should adopt an integrated, systematic approach. Despite adaptation plans – and even ICCA – adopting a sector-specific approach, cascading risks and how action in one sector may enhance or limit risks in another need to be better understood. Climate risks are interlinked and require systems-based responses. For example, the drought in spring 2020 during the COVID-19 pandemic nearly necessitated water restrictions when handwashing was vital for public health. A flood event in Donegal impacted Letterkenny hospital, leading to the closure of essential services. Large-scale power outages from storm events can cascade into problems across sectors if critical infrastructure is disrupted, as was evident from Storm Éowyn where damage to the power network cascaded to impact communications and water supplies. A purely sectoral approach can miss these cascading risks, and greater leadership is required to coordinate action across sectors, including key stakeholders and local communities in decision-making.

Traditionally, climate risks have been framed from a local perspective, but there is growing recognition that domestic risks resulting from climate-change impacts elsewhere – transboundary climate risks – form a significant gap in knowledge. Exposure to transboundary risks depends on economic openness, trade dependencies and country size (Challinor et al., 2018). As a highly open economy, Ireland is thus exposed and vulnerable to climate impacts and policy responses elsewhere, yet this is poorly reflected in current adaptation policy. Studies in the United Kingdom suggest that transboundary impacts on trade, investment and supply chains could be an order of magnitude greater than domestic climate-change impacts (Challinor & Benton, 2021).

As a shared island, collaborative adaptation between Northern Ireland and the Republic of Ireland is critical to building resilience (Murphy et al., 2024b). Key shared priorities include water and flood risk management, trade, agriculture, emergency response, public health, biodiversity and critical infrastructure. Existing efforts like the North South Ministerial Council and partnerships such as the Shared Island Dialogue offer innovative forums for transformative collaboration. However, barriers persist, including data-sharing, ownership of risk, competing priorities, resourcing and shared research funding opportunities (Murphy et al., 2024b).

To advance adaptation planning for transboundary risks, priorities should include developing methodologies for risk identification, monitoring and evaluation; guidance on prioritising risks in a rapidly changing world; collaboration at EU and international levels; assigning ownership of risks; and understanding risk transmission and amplification mechanisms (Harris et al., 2022). Input from the private sector will be crucial, especially for understanding critical supply chains and possible responses.

Focus on people and places

Climate risks are profoundly shaped by the exposure and vulnerability of people, ecosystems, resources, services, infrastructures, and economic, social and cultural assets. Moreover, the impacts of climate change and the benefits of adaptation will not be distributed equally across societies or geographies. Delving into these dimensions of risk is essential to address issues of fairness and equity in adaptation planning by examining who is most at risk, who stands to benefit, and why. Socio-economic vulnerability and the concept of just resilience have been inadequately addressed in national, sectoral and local

adaptation policies to date, and must become a central focus of future adaptation frameworks and plans (CCAC, 2022). The importance of just and fair adaptation is emphasised in the European Green Deal and the revised EU Adaptation Strategy (EC, 2021). Measuring progress towards realising a climate-resilient Ireland is impossible without understanding the dynamics of exposure and vulnerability.

Adaptation actions that are sustainable and result in just and fair adaptation or resilience, including procedural and distributive justice, need to be co-created with affected communities (Grainger et al., 2021). Lack of community engagement in developing adaptation strategies, especially when adaptation alters place-based relationships, has been shown to have detrimental impacts on well-being, increasing risks of maladaptation (Clarke et al., 2016; Clarke & Murphy, 2019; Phillips & Murphy, 2021; Phillips et al., 2022; Clarke & Murphy, 2023), escalating contestation, and ultimately raising intervention costs (Sweeney et al., 2013; Clarke et al., 2018). Farrell et al. (2023) demonstrated the multiple benefits of empowerment and the ultimate success and sustainability of adaptation when resilience-building prioritises engagement and co-production with communities affected by coastal change in Maharees, Co. Kerry. Adaptation resulting from co-creation tends to be more goal-oriented, respectful of diverse knowledge types, sensitive to place-associated values, pluralistic, inclusive, attentive to power dynamics, and provides opportunities for reflection and learning (Bolger et al., 2021). However, co-production is resource-intensive in terms of time and funding, often requiring skill sets and capacities not always readily available. Therefore, advancing adaptation requires investment in these skills and a commitment to co-producing adaptation measures. In particular, the higher education sector could help in developing capacity for co-production of place-based adaptation actions.

Frameworks for decision-making under uncertainty

Although most climate model projections agree on temperature increases, there is less consensus on how variables like precipitation will change over the coming decades. For instance, the magnitude and even direction of change in summer precipitation can vary depending on which climate model is used. Additionally, climate change does not happen in a vacuum; uncertain technological, socio-economic, and political changes are also expected to unfold. Adaptation occurs within this context, posing challenges for planners and decision makers.

Traditionally, adaptation decision-making has followed a top-down, science-first approach, using projected climate changes to assess local impacts – projections that often span large ranges. These broad uncertainties can stymie adaptation planning, leading decision makers to call for more research to reduce uncertainty or to default to the precautionary principle, which may result in excessive trade-offs or expensive adaptation (Murphy et al., 2011; Smith et al., 2018). More recently, research has focused on developing approaches for decision-making under deep uncertainty. These approaches, often categorised as bottom-up, typically involve working directly with decision makers to address existing vulnerabilities and evaluate the decision-making context and problems, rather than starting with climate-change impact projections (Wilby & Murphy, 2018; Wilby, 2022).

A core concept within these approaches is using models and data in an exploratory rather than predictive way to evaluate vulnerabilities and appraise the effectiveness and trade-offs between adaptation options – even the sequencing of adaptation actions (Vaghefi et al., 2021). Numerous frameworks exist, including dynamic adaptive policy pathways (Haasnoot et al., 2013), adaptive policy-making (Kwakkel et al., 2010), real options analysis (Woodward et al., 2014), info-gap decision theory (Ben-Haim, 2006), decision scaling (Brown et al., 2012), and robust decision-making (Groves & Lempert, 2007). These approaches are valuable for specific projects and critical infrastructure where there are potentially large investment decisions, high vulnerability, or significant trade-offs and opportunity costs.

Because of unavoidable uncertainty, decision makers are advised to seek robust decisions that perform satisfactorily across a range of plausible futures, offer benefits now and in the future, and develop flexible plans that can adapt over time as the future unfolds (Hallegatte, 2009). They also leverage information beyond just climate model projections, including historical extremes and understanding of key drivers in the climate system. For example, developing storylines is an approach that uses historical extremes, large ensembles of climate model projections, and stakeholder knowledge to create plausible scenarios of how specific extreme events and vulnerabilities may unfold in the future. These storylines can improve risk awareness, identify failure points, stress-test adaptation decisions, incorporate compound risks, and explore the boundaries of plausibility, thus avoiding false precision and surprise (Shepherd et al., 2018).

Recognise the risks and limits of adaptation

Adaptation actions can themselves entail risks, termed 'response risks' by the IPCC sixth assessment report. These include the possibility of adaptation measures being ineffective or unjust, leading to unintended adverse effects on individuals, constraining their ability to meet other societal objectives, or hindering others from adapting to climate change. Maladaptation is a response risk and refers to potentially adverse outcomes of certain adaptation actions, such as increasing greenhouse gas emissions (e.g. using fossil fuel-powered air conditioners to cope with heat extremes), escalating vulnerability to climate change, reducing welfare or well-being, or increasing vulnerability for specific populations now or in the future (Ara Begum et al., 2022).

Actions taken today may set resource allocations and decision pathways that limit future generations' choices, increasing the risk of creating lock-in effects that constrain future resilience. Maladaptation has been widely studied and is often associated with human, financial, and technical resource constraints; lack of transparency or capacity in decision-making and governance; absence of key policy guidance; entrenched institutional, legal, and technical world-views; exclusion of vulnerable groups or those affected by adaptation from the decision-making process; and top-down planning approaches disconnected from local dynamics and needs (Ara Begum et al., 2022).

Not all adaptation actions reduce risk, and some may have negative consequences. For instance, Phillips and Murphy (2021) show how installation of hard defences against coastal erosion in County Wexford resulted in amplifying a sense of loss of place with negative impacts on community well-being. Maximising the likelihood of successful adaptation requires focusing on the principles of just adaptation, maintaining flexibility and response options to avoid lock-in and to increase resilience, and ensuring satisfactory well-being outcomes for those affected (Quinn et al., 2023). Understanding the sustainability of adaptation measures is critical to avoiding maladaptation and necessitates assessments of current and future vulnerabilities, along with monitoring programmes and subsequent evaluations of adaptation interventions. These aspects should be a priority for future research into learning for adaptation.

The effectiveness of adaptation depends on several factors, including the speed and magnitude of climate-change impacts and the constraints and limits that human and natural systems face when confronted with increasing levels of climate risk. Adaptation limits

refer to the point at which adaptive actions no longer suffice, resulting in the inability of those affected to meet their needs – such as resources, ecosystem services, health, and well-being – from the impacted sector or system. Adaptation limits are defined as either hard or soft. Hard limits occur when the speed or magnitude of change is such that no adaptive actions can avoid intolerable risks (Dow et al., 2013). For resilience, hard adaptation limits represent a level of change within a system that negates its ability to maintain essential functions and structure. Ecosystems such as peatlands and many species are often associated with environmental thresholds beyond which they cannot adapt. Similarly, hard adaptation limits may be encountered in response to sea-level rise, resulting in relocation of communities.

Soft adaptation limits occur when adaptive options exist but are unavailable or cannot be deployed due to reasons like financial constraints or lack of social acceptance. Adaptation limits can arise from complex interactions among social, cultural, ecological, technological and climate factors that have thresholds beyond which adaptation becomes unfeasible (Ara Begum et al., 2022). For soft limits, thresholds are endogenous to society and are contingent on ethics, knowledge, culture, governance, institutions and policies (Tschakert et al., 2017). Constraints on adaptation – including financial, governance and institutional barriers – can lead to soft adaptation limits. Adger et al. (2013), using the 2009 floods in the west of Ireland as an example, show how contestation over primary causes of floods and associated responsibilities for action can lead to a breakdown in social contracts for adaptation. O'Brien (2009) argues that adaptation limits may also manifest as the irreversible loss of places and identities that people value, raising important questions about the role of social values in adapting to climate change. Many limits to adaptation relate to social values, culture and risk perceptions. These areas are understudied in the Irish context, and insights would be beneficial to ensuring the success of adaptation actions. Where limits are encountered, they may only be overcome by transformational adaptation.

Widen the solution space

The concept of the solution space – defined as the area within which opportunities and constraints determine why, how, when, and who adapts to climate risks – helps expand the set of effective, feasible, and just solutions (Haasnoot et al., 2020). A larger solution space indicates

that people and organisations have more options for adapting to and reducing their risk from climate change. Schipper et al. (2022) highlight that widening the solution space requires leveraging interdisciplinary knowledge and bringing new ways of thinking and knowledge systems to inform action that embraces plurality and complexity, avoiding purely reductionist approaches.

In addition to traditional scientific, engineering and economic approaches, working with nature through so-called nature-based approaches and integrating local knowledge are important but under-implemented strategies for widening the solution space. Nature-based approaches involve actions that benefit people and biodiversity, while reducing climate risks. They range from restoring degraded ecosystems – which can offer multiple co-benefits like risk reduction, mitigation and biodiversity enhancement – to integrating nature-based approaches into urban environments, such as sustainable drainage systems to reduce flooding. Improved management of Ireland's peatlands, for example, offers both mitigation and adaptation benefits, particularly in relation to biodiversity, flood and water resource management. Indigenous knowledge relevant to Ireland can include aspects such as agro-environmental stewardship and practices to support biodiversity, reduce erosion and manage flooding. In coastal communities, knowledge of local tides, storm patterns and fish migration can be important to the success of adaptation and are not always available to 'external' experts.

Effective nature-based climate change adaptation stems from inclusive decision-making and adaptive management pathways that deliver climate-resilient systems serving multiple SDGs. However, as with any adaptation solution, poorly conceived and designed nature-based efforts can result in maladaptation, with potential negative impacts on human well-being and sustainability (Schipper, 2020). Nature-based approaches explicitly recognise and integrate the vulnerability of ecosystems with that of socio-economic systems, aligning climate change mitigation with adaptation. Seddon et al. (2020) highlight growing evidence that protecting, restoring and managing natural forests and wetlands in catchments can regulate water quality and supplies, reduce flood risk, and decrease susceptibility to soil loss through erosion and landslide risks. In Ireland, Collier and Bourke (2020) advocate for mainstreaming nature-based approaches in integrated catchment management, offering multiple co-benefits for adaptation, while Farrell et al. (2023) explore opportunities and lessons from such approaches in coastal

domains. However, challenges in implementing nature-based approaches include measuring their effectiveness at reducing risk, identifying effective contexts, mobilising investment, increasing implementation capacity, and overcoming governance hurdles (Collier & Bourke, 2020; Seddon et al., 2020).

Novel research, implementation and monitoring of nature-based approaches are ongoing in Ireland, including in flood risk management (Collier & Bourke, 2020), water quality, coastal management (Farrell et al., 2023), and urban contexts (Scott & Lennon, 2016; Collier et al., 2023). Such efforts need further support through opportunities for developing test spaces and monitoring outcomes, which are critical for mainstreaming nature-based approaches into adaptation policy (Farrell et al., 2023). Realising a climate-resilient Ireland will require deploying multiple adaptation strategies, with nature-based approaches becoming an increasingly important part of the adaptation portfolio.

Increasingly, adaptation research recognises the importance of diverse forms of knowledge – including scientific (both natural and social sciences), indigenous and local – in achieving effective and just outcomes in reducing climate risks. Enhancing knowledge on risks, impacts, vulnerabilities, and adaptation options promotes societal and policy responses. Embracing top-down, bottom-up, and co-produced collaborative knowledge production processes can deepen capacity-building, widen the solution space and ensure justice in adaptation outcomes (Ara Begum et al., 2022).

Monitoring and evaluation progress and outcomes

Monitoring and evaluation (M&E) is a challenging yet critical component of climate adaptation. It is essential for understanding the progress made in reducing climate risks, assessing the success of measures in terms of outcomes, avoiding maladaptation, and learning to improve subsequent strategies and policies. The Paris Agreement encourages countries to engage in monitoring, evaluating, and learning from adaptation plans, policies, programmes and actions.

Distinctions between M&E typically view monitoring as assessing the progress of adaptation implementation – such as the number of actions commenced or completed, or the number of people trained – while evaluation is a more comprehensive assessment of achievements, unintended effects and lessons learned. M&E serves multiple purposes, including determining whether actions have had the intended impact in reducing climate risks (including vulnerability

and exposure); increasing resilience or adaptive capacity; informing ongoing implementation and future plans; and providing accountability. Effective communication of M&E findings and feedback into decision-making processes is crucial to facilitate learning.

However, to date, emphasis in Ireland (and elsewhere) has been placed on monitoring implementation, with little effort at assessing the outcomes of adaptation interventions to extract key lessons for learning and improving progress (New et al., 2022). To enhance M&E, additional effort is needed to assess the nuances of implementation – the challenges and opportunities encountered – and the outcomes of adaptation. This will require support in developing frameworks, as there is a lack of metrics upon which to report outcomes, unlike mitigation. Furthermore, how adaptation is framed – as a technical or sociopolitical challenge – can shape our understanding of progress, outcomes and management (Singh et al., 2022).

As the implementation of adaptation actions has grown since the development of adaptation plans, there is a pressing need to examine outcomes at different scales – local, sectoral and national – for effectiveness, adequacy, and justice/equity aspects of processes and outcomes, as well as synergies and trade-offs with mitigation and other socio-economic and environmental goals. For success to be measured, it is crucial that all adaptation actions are associated with clear aims and objectives. Success in adaptation outcomes is not a simple dichotomy between success and failure or maladaptation; rather, outcomes need to be evaluated along an adaptation–maladaptation continuum relative to established criteria (New et al., 2022).

Embrace climate-resilient development

Development decisions in a changing climate need to include choices and actions that reduce emissions and adapt to climate risks to sustain development over time. Development processes can enhance vulnerability, while poorly designed climate action and maladaptation can detract from sustainable development (Werners et al., 2021). Climate-resilient development is a process of implementing mitigation and adaptation to support sustainable development for all. It emphasises integrative interventions within sectors or regions that address the socially and spatially uneven distribution of climate risks and extends the goals of climate action beyond risk reduction to improving social, economic and ecological outcomes (Schipper et al., 2022).

By taking a systematic approach, climate-resilient development strengthens sustainable development and aims to promote fair and equitable approaches to mitigation and adaptation, offering multiple co-benefits for society and nature. Climate-resilient development pathways emerge from the choices of multiple actors across scales – including government, business, civil organisations, communities and individuals – and represent the results of negotiation and cooperation among actors. Rather than identifying single adaptation interventions, climate-resilient pathways enable a mix of adaptation, mitigation and development appropriate to contexts and shared goals. They unfold in ways consistent with the principles of equity and social justice, thereby expanding the solution space and avoiding fragmentation of adaptation efforts. Crucially, the idea of pathways is that resilience is not a fixed outcome but a process of negotiation and management that can be achieved through a combination of incremental and transformative changes that improve livelihoods, social and economic well-being, and responsible environmental management. A novel application of such climate-resilient development planning is offered by Farrell et al. (2023) in the context of community adaptation responses to rising sea levels and coastal erosion in Maharees.

Conclusion: Where to from here?

Despite the challenges and gaps that exist, there are reasons for optimism in adaptation. Foundations are being laid, based on improved climate knowledge and robust information, and actions are being implemented. Investment in research is addressing knowledge gaps. Adaptation is now mandated in national legislation, integrated with EU policy, and governance structures and oversight mechanisms have been established. Many sectors and local authorities have developed their first adaptation plans. Reflection upon and learning from these will underpin advances in adaptation. Investment in climate action regional offices is supporting the development of capacity, from local to national level. The importance of effective climate services, community engagement and widening of adaptation actions to include nature-based approaches, and non-structural measures, is being increasingly recognised. Examples of good and bad adaptation outcomes are emerging and provide the foundation for learning and doing better. Through the NAF, Ireland is striving for a just and fair transition in which there is climate action, upgraded

infrastructure, and improved services for people and the natural environment.

While progress is being made, greater efforts are needed to speed up implementation. While the framing of resilience in the NAF is shifting towards a more people-centred approach, this is not strongly reflected in sectoral and local authority plans. Some of this challenge may relate to poor coherence of policy across scales. For instance, the updated NAF in 2024 was released late in the development of LACAPs, while sectoral plans are due to be updated in 2025, the current versions are part of the 2018 NAF. Similarly, sectoral plans are being developed after local plans. Stronger policy coherence is therefore necessary to ensure better coordination and that implementation is not ad hoc and reflects the priorities of the updated NAF.

Sustained and equitable financing mechanisms are needed to foster resilience. Current funding models, including the Local Authority Climate Action Fund, have improved financial access for local adaptation efforts. However, reliance on competitive funding mechanisms can exclude under-resourced communities and sectors. Establishing long-term, structured funding streams will be critical for scaling up and sustaining adaptation initiatives. Developing systematic cross-sectoral risk assessments and collaborative planning frameworks will enable co-benefits and improved resilience to cascading climate impacts. More integrated, long-term, and cross-sectoral strategies are needed to ensure systemic resilience to climate change. At the core is the need for greater political buy-in. While climate resilience is recognised as a national priority, political commitment remains inconsistent across sectors and governance levels. The lack of mandatory adaptation planning in key areas and insufficient coordination between government departments limits progress. Public and community engagement needs to be deepened and sustained. While community participation is improving at the local level, national-level adaptation remains largely government-driven, with limited public involvement. Strengthening co-creation mechanisms, participatory planning, and direct engagement with communities will help build locally relevant and socially just adaptation measures. Resilience needs to be more than simply retaining the status quo.

Finally, without effective adaptation and proactive planning, climate shocks could drive unplanned transformations. Sea-level rise and extreme events, such as severe and prolonged droughts (that we have already seen in the historical record) or slowdown in the Atlantic

meridional overturning circulation, could exceed current adaptation and resilience planning limits. If proactive adaptation measures are not taken, future responses may be dictated by crisis-driven transformations rather than strategic, sustainable adaptation.

References

Adger, W. N. et al. (2013). Changing social contracts in climate-change adaptation. *Nature Climate Change, 3*(4), 330–3. https://doi.org/10.1038/nclimate1751

Ara Begum, R. et al. (2022). Point of departure and key concepts. In H.-O. Pörtner et al. (Eds.), *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 121–96). Cambridge University Press.

Ben-Haim, Y. (2006). *Info-gap Decision Theory: Decisions under severe uncertainty.* Academic Press.

Bolger, P. et al. (2021). *Better together: Knowledge co-production for a sustainable society.* Royal Irish Academy. https://cora.ucc.ie/server/api/core/bitstreams/499995b2-fd36-43a1-879a-b8d5bc04d218/content

Brown, C., et al. (2012). Decision scaling: Linking bottom-up vulnerability analysis with climate projections in the water sector. *Water Resources Research, 48*(9), W09537. https://doi.org/10.1029/2011WR011212

Challinor, A. & Benton, T. G. (2021). *UK climate risk independent assessment (CCRA3) – Technical report chapter 7: International dimensions.* UK Climate Risk, London. www.ukclimaterisk.org/wp-content/uploads/2021/06/CCRA3Chapter-7-FINAL.pdf

Challinor, A. J. et al. (2018). Transmission of climate risks across sectors and borders. *Philosophical Transactions of the Royal Society A. Mathematical Physical Engineering Sciences, 376*, 2121. https://doi.org/10.1098/rsta.2017.0301

Clarke, D. & Murphy, C. (2019). *Challenges of transformative climate change adaptation: Insights from flood risk management.* Environmental Protection Agency. www.epa.ie/publications/research/climate-change/Research_ Report_265.pdf

Clarke, D. & Murphy, C. (2023). Incremental adaptation when transformation fails: The importance of place-based values and trust in governance in avoiding maladaptation. *Journal of Environmental Psychology, 88*, 102037. https://doi.org/10.1016/j.jenvp.2023.102037

Clarke, D. et al. (2016). Barriers to transformative adaptation: Responses to flood risk in Ireland. *Journal of Extreme Events, 3*(2), 1650010. https://doi.org/10.1142/S234573761650010X

Clarke, D. et al. (2018). Place attachment, disruption and transformative adaptation. *Journal of Environmental Psychology, 55*, 81–9. https://doi.org/10.1016/j.jenvp.2017.12.006

Clarke, B. et al. (2024). *Climate change made the extreme 2-day rainfall event associated with flooding in Midleton, Ireland more likely and more intense*. World Weather Attribution report. www.worldweatherattribution.org/climate-change-made-the-extreme-rainfall-associated-with-flooding-in-midleton-ireland-more-likely-and-more-intense/

Climate Action and Low Carbon Development Act. (2015). www.irishstatutebook.ie/eli/2015/act/46/enacted/en/html

Climate Change Advisory Council. (2021). *Annual review 2021*. www.climatecouncil.ie/councilpublications/annualreviewandreport/CCAC_AnnualReview_2021%20web.pdf

Climate Change Advisory Council. (2022). *Annual review 2022*. www.climatecouncil.ie/councilpublications/annualreviewandreport/Annual%20Review%202022%20Web%20Version.pdf

Climate Change Advisory Council. (2023). *Annual review 2023.* www.climatecouncil.ie/councilpublications/annualreviewandreport/CCAC-AR-2023-postfinal.pdf

Climate Change Advisory Council. (2024). *Annual review 2024: Preparing for Ireland's changing climate.* www.climatecouncil.ie/councilpublications/annualreviewandreport/AR2024-Adaptation-3P.pdf

Coll, J. et al. (2013). *Current and future vulnerabilities to climate change in Ireland*. Climate Change Research Programme (CCRP) 2007–2013, Report Series No. 29. Environmental Protection Agency. www.epa.ie/publications/research/climate-change/current-and-future-vulnerabilities-to-climate-change-in-ireland.php

Collier, M. J. & Bourke, M. (2020). The case for mainstreaming nature-based solutions into integrated catchment management in Ireland. *Biology and Environment, Proceedings of the Royal Irish Academy*, *120B*(2), 107–13. http://dx.doi.org/10.3318/BIOE.2020.08

Collier, M. J. et al. (2023). An integrated process for planning, delivery, and stewardship of urban nature-based solutions: the Connecting Nature Framework. *Nature-Based Solutions, 3*, 100060. https://doi.org/10.1016/j.nbsj.2023.100060

Cote, M. & Nightingale, A. J. (2011). Resilience thinking meets social theory: Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography*, *36*(4), 475–89. https://doi.org/10.1177/0309132511425708 (Original work published 2012)

Cretney, R. (2014). Resilience for whom? Emerging critical geographies of socio ecological resilience. *Geography Compass*, *8*(9), 627–40. https://doi.org/10.1111/gec3.12154

Cutter, S. L. (2016). Resilience to what? Resilience for whom? *The Geographical Journal*, *182*(2), 110–3. https://doi.org/10.1111/geoj.12174

Department of the Environment, Climate and Communications. (2018). *National adaptation framework: Planning for a climate resilient Ireland*. Government of Ireland. www.gov.ie/pdf/?file=https://assets.gov.ie/76430/d35c3843-29c7-419a-b48bad5db2bfb118.pdf#page=null

Department of the Environment, Climate and Communications. (2022). *Review of the national adaptation framework.* Government of Ireland. https://assets.gov.ie/249476/18045db6-e38e-4b6a-a0ab-c48479acf059.pdf

Department of the Environment, Climate and Communications. (2024). *National adaptation framework: Planning for a climate resilient Ireland.* Government of Ireland. https://assets.gov.ie/281278/ac892520-3f2a-4964-8c8a-7406c931d287.pdf

Dow, K. et al. (2013). Limits to adaptation. *Nature Climate Change, 3*(4), 305–7. https://doi.org/10.1038/nclimate1847

European Commission. (2021). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Forging a Climate-resilient Europe – The new EU Strategy on Adaptation to Climate Change*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN

Farrell, E. et al. (2023). *Building coastal and marine resilience in Ireland*. Environmental Protection Agency. www.epa.ie/publications/research/epa-research-2030-reports/Research_Report_429.pdf

Grainger, S. et al. (2021). Barriers and opportunities for actionable knowledge production in drought risk management: embracing the frontiers of co-production. *Frontiers in Environmental Science, 9*, 602128. https://doi.org/10.3389/fenvs.2021.602128

Groves, D. G. & Lempert, R. J. (2007). A new analytic method for finding policy-relevant scenarios. *Global Environmental Change, 17*(1), 73–85. https://doi.org/10.1016/j.gloenvcha.2006.11.006

Haasnoot, M. et al. (2013). Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change, 23*(2), 485–98. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Haasnoot, M. et al. (2020). Defining the solution space to accelerate climate change adaptation. *Regional Environmental Change*, *20*, 1–5. https://doi.org/10.1007/s10113-020-01623-8

Hallegatte, S. (2009). Strategies to adapt to an uncertain climate change. *Global Environmental Change, 19*(2), 240–7. https://doi.org/10.1016/j.gloenvcha.2008.12.003

Harris, K. et al. (2022). Rising to a new challenge: A protocol for case-study research on transboundary climate risk. *Weather Climate, and Society*, *14*(3), 755–68. https://doi.org/10.1175/WCAS-D-21-0022.1

Intergovernmental Panel on Climate Change. (2019). Summary for policymakers. In H. -O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. M. Weyer (Eds.), *IPCC special report on the ocean and cryosphere in a changing climate* (pp. 3–35). Cambridge University Press. https://doi.org/10.1017/9781009157964.001

Intergovernmental Panel on Climate Change. (2023). Summary for policymakers. In Core Writing Team, H. Lee & J. Romero (Eds.), *Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the sixth assessment report of the Intergovernmental Panel on Climate Change.* doi: 10.59327/IPCC/AR6-9789291691647.001

Kwakkel, J. H. et al. (2010). Classifying and communicating uncertainties in model-based policy analysis. *International Journal of Technology, Policy, and Management*, *10*(4), 299–315. https://doi.org/10.1504/IJTPM.2010.036918

McGookin, C. et al. (2024). *Ireland's climate change assessment. Volume 2: Achieving climate neutrality by 2050*. Environmental Protection Agency. http://www.epa.ie/publications/monitoring—assessment/climate-change/irelands-climate-change-assessment-volume-2.php

Moriarty, R. et al. (2024). *Ireland's climate change assessment. Volume 4: Realising the benefits of transition and transformation*. Environmental Protection Agency. www.epa.ie/publications/monitoring—assessment/climate-change/irelands-climate-change-assessment-volume-4.php

Murphy, C. et al. (2011). Against a 'wait and see' approach in adapting to climate change. *Irish Geography, 44*(1), 81–95. https://doi.org/10.55650/igj.2011.36

Murphy, C., et al. (2023). The emergence of a climate change signal in long-term Irish meteorological observations. *Weather and Climate Extremes*, *42*, 100608. https://doi.org/10.1016/j.wace.2023.100608

Murphy, C. et al. (2024a). *Ireland's climate change assessment. Volume 3: Being prepared for Ireland's future climate*. Environmental Protection Agency. www.epa.ie/publications/monitoring—assessment/climate-change/irelands-climate-change-assessment-volume-3.php

Murphy, C. et al. (2024b). *Transboundary climate Risks for the island of Ireland (TCRII).* Technical Report. Environmental Protection Agency. www.epa.ie/publications/research/climate-change/Research_Report-449.pdf

New, M. et al. (2022). Decision-making options for managing risk. In H.-O. Pörtner et al. (Eds.), *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 2539–654). Cambridge University Press.

Noone, C. et al. (2024). Ireland's climate change assessment. Volume 1: Climate science – Ireland in a changing world. Environmental Protection

Agency. www.epa.ie/publications/monitoring—assessment/climate-change/irelands-climate-change-assessment-volume-1.php

O'Brien, K. L. (2009). Do values subjectively define the limits to climate change adaptation. In W. N. Adger et al. (Eds.), *Adapting to climate change: Thresholds, values, governance* (pp.164–80). Cambridge University Press.

Phillips, C. & Murphy, C. (2021). Solastalgia, place attachment and disruption: insights from a coastal community on the front line. *Regional and Environmental Change, 21*(2), 46. https://doi.org/10.1007/s10113-021-01778-y

Phillips, C. et al. (2022). The impacts of and responses to place loss in a coastal community in Ireland. *Local Environment*, *27*(7), 879–96. https://doi.org/10.1080/13549839.2022.2078294

Quinn, T. et al. (2023). Health and wellbeing implications of adaptation to flood risk. *Ambio*, *52*(5), 952–62. https://doi.org/10.1007/s13280-023-01834-3

Schipper, E. L. F. (2020). Maladaptation: When adaptation to climate change goes very wrong. *One Earth, 3*(4), 409–14. https://doi.org/10.1016/j.oneear.2020.09.014

Schipper, E. L. F. et al. (2022). Climate resilient development pathways. In H.-O. Pörtner et al. (Eds.), *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 2655–807). Cambridge University Press. https://doi:10.1017/9781009325844.027

Scott, M. & Lennon, M. (2016). Nature-based solutions for the contemporary city. *Planning Theory & Practice, 17*(2), 267–300. https://doi.org/10.1080/14649357.2016.1158907

Seddon, N. et al. (2020). Global recognition of the importance of nature-based solutions to the impacts of climate change. *Global Sustainability*, 3, e15. https://doi.org/10.1017/sus.2020.8

Shepherd, T. G. et al. (2018). Storylines: An alternative approach to representing uncertainty in physical aspects of climate change. *Climate Change*, *151*, 555–71. https://doi.org/10.1007/s10584-018-2317-9

Singh, C. et al. (2022). Interrogating 'effectiveness' in climate change adaptation: 11 guiding principles for adaptation research and practice. *Climate and Development, 14*(7), 650–64. https://doi.org/10.1080/17565529.2021.1964937

Smith, K. A. et al. (2018). Navigating cascades of uncertainty – as easy as ABC? Not quite …. *Journal of Extreme Events, 5*(1), 1850007. https://doi.org/10.1142/S2345737618500070

Sweeney, J. et al. (2013). *Co-ordination, communication and adaptation for climate change in Ireland: An integrated approach (COCOADAPT).* Climate Change Research Programme (CCRP) 2007–2013. Report Series No. 30. Environmental Protection Agency.

Tschakert, P. et al. (2017). Climate change and loss, as if people mattered: Values, places, and experiences. *Wiley Interdisciplinary Reviews, Climate Change, 8*(5), e476. https://doi.org/10.1002/wcc.476

United Nations Framework Convention on Climate Change secretariat. (2016). The Paris Agreement. https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf

United Nations General Assembly. (2015). Transforming our world: The 2030 Agenda for Sustainable Development. Resolution A/RES/70/1. https://docs.un.org/en/A/RES/70/1

Vaghefi, S. A. et al. (2021). Using decision making under deep uncertainty (DMDU) approaches to support climate change adaptation of Swiss ski resorts. *Environmental Science & Policy, 126*, 65–78. https://doi.org/10.1016/j.envsci.2021.09.005

Werners, S. E. et al. (2021). Advancing climate resilient development pathways since the IPCC's fifth assessment report. *Environmental Science & Policy, 126*, 168–76. https://doi.org/10.1016/j.envsci.2021.09.017

Wilby, R. L. (2022). *Working Paper No. 12: Well informed adaptation decision making under uncertainty.* Climate Change Advisory Council. www.climatecouncil.ie/councilpublications/councilworkingpaperseries/Working%20Paper%20No.%2012.pdf

Wilby, R. & Murphy, C. (2018). Decision-making by water managers despite climate uncertainty. In W. T. Pfeffer, et al. (Eds.), *The Oxford handbook of planning for climate change hazards*. Oxford University Press. https://academic.oup.com/editedvolume/35480/chapter-abstract/303907472?redirectedFrom=fulltext

Woodward, M. et al. (2014). Adaptive flood risk management under climate change uncertainty using real options and optimization. *Risk Analysis*, *34*(1),75–92. https://doi.org/10.1111/risa.12088