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Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

Climate Change Research Programme (CCRP) 2007-2013
Report Series No. 29

Current and future vulnerabilities to climate change in Ireland

SSTI
Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

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EPA STRIVE Programme 2007–2013

Current and future vulnerabilities to climate change in Ireland

(2010-CCRP-DS-2.3)

End of Project Report

Prepared for the Environmental Protection Agency

by

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ACKNOWLEDGEMENTS

This report is published as part of the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007–2013. The programme is financed by the Irish Government under the National Development Plan 2007–2013. It is administered on behalf of the Department of the Environment, Community and Local Government by the Environmental Protection Agency which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to thank their ICARUS colleague Jackie McGloughlin for numerous helpful discussions on elements of this work. John Coll would also like to thank her for reviewing and commenting on earlier versions of this report. The authors would very much like to thank all of those in government departments and agencies, non-governmental organisations and other groups who contributed to this work (a list of workshop participants is supplied in Appendix 2). By giving freely of their time, insight and expert knowledge, they have added considerable value to this work.

DISCLAIMER

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

EPA CLIMATE CHANGE RESEARCH PROGRAMME 2007–2013

Published by the Environmental Protection Agency, Ireland

PRINTED ON RECYCLED PAPER

ISBN:
Price: €

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Executive summary

1. Introduction to the project

Vulnerability assessment is a key aspect of anchoring the potential impacts of climate change to present development planning. In developing a national climate change strategy for Ireland, an assessment of vulnerability at an early stage is essential in order to inform subsequent stages of the process.

The key goal of this assessment is to identify first-generation vulnerabilities for Ireland based on a sensitivity analysis across the key sectors. Strengthened by input from stakeholders with considerable expertise across the sectors, the results characterise the most vulnerable sectors ahead of a fuller climate change risk assessment which can inform subsequent adaptation options.

The assessment also recognises the shift in emphasis away from better defining exposure and potential impacts to a better understanding of the factors that affect societies' and systems' sensitivity to those impacts and their capacity to adapt. This reflects the increasing recognition of the importance of considering social vulnerability alongside biophysical vulnerability. In essence this is a reflection of the shift in conceptual thinking away from a top-down scenario and impacts-first approach to a bottom-up vulnerability and thresholds-first approach.

2. The project in context

This process of garnering stakeholder input recognised that the prioritisation of key areas for adaptation to climate change should be carried out in Ireland as part of an on-going national vulnerability scoping study. The input from stakeholders also recognised that while quantitative vulnerability assessments can incorporate a wide range of geospatial data to characterise exposure and sensitivity of assets across geographic units, such assessments have difficulty in incorporating context-specific knowledge of system sensitivity and adaptive capacity. Such information is often not easily represented geospatially and instead is best supplied qualitatively by local stakeholders.

The results of the National Adaptive Capacity assessment indicate that Ireland is in the early stages of the adaptation process, but also emphasise the need for a vulnerability and risk assessment in order to prioritise and frame subsequent adaptation needs and options. There is also recognition that the most effective strategy for adaptation planning is to integrate climate change adaptation into policies, plans, programmes and projects at all levels of government and across all sectors. Additionally, there is a growing awareness that adaptation to climate change needs an integrated approach involving all stakeholders on all institutional levels.

First-generation vulnerability assessments raise awareness of the (pre-adaptation) vulnerability of valued systems to climate change and may also assess the relative importance of various climatic and non-climatic factors. By doing so they help to prioritise further research and determine the need for mitigation and adaptation measures to reduce adverse effects of climate change. However, until the feasibility of implementing adaptations is assessed, an assessment cannot provide a full picture of the vulnerability for any given system.

3. Results summary

The preliminary analysis identified a clustering of impacts and their importance in relation to an assessment of likely resilience by sector. The assessment methodology used was akin to an impacts-first, science-first, or classical approach. This identified where some of the key sensitivities lie, and by weighing up sensitivity versus the impact, the initial results can be also be interpreted as a 'best estimate' of first-generation vulnerability.

To maximise the added value from the stakeholder input, a modification of a deliberative risk-ranking methodology was applied. The Vulnerability Scoping Diagram allows for rapid assessment and multiple stakeholder perspectives of vulnerability. This technique is based on methods of deliberative risk evaluation, and the goal was to engage stakeholders and sector practitioners collectively to provide qualitative contextual risk rankings as a first step in a vulnerability assessment.

The two exercises delivered broadly similar assessments for certain sectors, although the results differed markedly for others. In the impacts-led assessment, natural resources (biodiversity and fisheries) and the built infrastructure (including coastal areas) emerged as the most vulnerable sectors, followed by agriculture, water resources and forestry.

The stakeholder assessment also deemed biodiversity and fisheries to be the most vulnerable sectors, but delivered a more mixed assessment for agriculture and forestry, e.g. where they considered that the sensitivities were offset by the adaptive capacity. Water resources also emerged as potentially vulnerable in the stakeholder-led assessment, as did coastal resources. However, compared to the impacts-led approach, the stakeholder assessment for the built environment was more mixed, with an assessment that the sensitivities were offset to some extent by the adaptive capacity.

5. Specific recommendations

Within the conceptual framework used, what is presented here is a pre-adaptation assessment of vulnerability. In essence the results represent a preliminary first-generation vulnerability assessment strengthened by stakeholder input. What should follow is a full climate change risk assessment across the sectors to more fully inform a coherent national adaptation response.

For all the sectors further research is required to identify critical thresholds or adaptation tipping points. These would help in answering the basic adaptation questions of decision- and policy-makers and help to frame new ones. Uncertainty about climate change is unlikely to be significantly reduced in the short term, but neither can a ‘wait and see’ strategy be adopted.

Therefore, future research should encompass an integrated scenarios–impacts (top-down) and vulnerability–thresholds (bottom-up) approach. Rather than trying to predict impacts through individual scenarios, such an integrated approach would help identify the triggers, or critical thresholds, that signal a state of vulnerability for any given sector.

Throughout all cycles of policy implementation and review, the options for climate change adaptation including the assessment of vulnerability must remain part of an iterative process. Therefore, as access to information is improved by better data and refined by better models, decision-making quality can be expected to improve steadily.

Notwithstanding the uncertainties associated with the climate change projections, and the discourse surrounding the assessment methodologies themselves, the priority sectors for further investigation are:

- Biodiversity and fisheries;
- Water resources and the built coastal environment;
- Forestry and agriculture.

1. Introduction

In developing a national climate change strategy for Ireland, an assessment of vulnerability at an early stage is essential in order to inform subsequent stages of the process. This has to take account of a wide range of direct impacts within Ireland, including: changing precipitation patterns and river flow regimes, sea-level rise, possible heat extremes and seasonal droughts, alongside changing patterns of health-related risks such as allergies, heatstroke and vector-borne diseases. However, these also have to be considered alongside a comprehensive assessment of sensitivity and adaptive capacity on a sector-by-sector basis. The approach also has to be inclusive if human and natural systems are viewed as intimately coupled and differentially exposed, sensitive and adaptive to threats (Polsky *et al*., 2007).

Vulnerability assessment is a key aspect of anchoring assessments of climate change impacts to present development planning. Recognising that multiple definitions of vulnerability exist, this study chooses to apply the Intergovernmental Panel on Climate Change (IPCC) definition as an operational definition of vulnerability:

Vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change.

Based on this, a key goal is to identify first-generation vulnerabilities based on a sensitivity analysis across the key sectors. It is anticipated that these will characterise the priority risks ahead of a fuller climate change risk assessment that can inform subsequent adaptation actions.

1.1. Framing the priorities

An earlier version of this document was used to brief actors and stakeholders across the sectors further to eliciting their workshop input to a first-generation vulnerability assessment (*sensu* Füssel and Klein, 2006) for Ireland. Stakeholder input was sought on the basis that while quantitative vulnerability assessments can incorporate a wide range of geospatial data to characterise exposure and sensitivity of assets across geographic units, such assessments have difficulty in incorporating context-specific knowledge of system sensitivity and adaptive capacity. Such information is often not easily represented geospatially and instead is best informed qualitatively by local stakeholders. The stakeholder engagement also recognised that a holistic approach is fundamental to a vulnerability perspective, and that this complicates the analytical task compared to, for example, an impacts-only led assessment. Consequently, this input was especially important for a short project with relatively limited resources operating primarily on a scoping brief. The collated results from the stakeholder workshop are organised and presented in Section 6 here.

This process of stakeholder input recognised that the prioritisation of key areas for adaptation to climate change (where, how, to whom) should be carried out in Ireland as part of an ongoing national vulnerability scoping study (Shine and Desmond, 2011). Accordingly, this is an essential next step in further developing climate change adaptation policy, planning and implementation, and inputs from local government and sectors are required to inform the priority areas (Shine and Desmond, 2011). There is already buy-in from government departments to engage with the adaptation process in a more structured manner by drawing up sectoral plans identifying the climate risk to their sector, assessing their vulnerability to such risks and developing relevant adaptation options (Casserly, 2012). The imminent EU Adaptation Strategy is also expected to place monitoring and reporting requirements for adaptation on Member States, which will further accelerate this process.

The results presented here recognise that priorities are likely to change over time as impacts are better understood and adaptive capacity increases, and that a system will need to be put in place for ongoing review and adjustment (Desmond and Shine, 2011). This recognition that a flexible, adaptive and iterative strategy is required due to uncertainties is emphasised throughout this report and was highlighted in the briefing to the Consultation Seminar participants ahead of the day (Annex 1).

2. Background

2.1. Global and European dimensions of projected climate change

2.1.1. Observed changes in climate

Observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising sea level are unequivocal evidence of warming of the climate system globally. Global mean temperature has increased by 0.8°C compared with pre-industrial times for land and oceans, and by 1.0°C for land alone (EEA, 2008). Most of the observed increase in global average temperatures is very likely due to increases in anthropogenic greenhouse gas concentrations (Albritton *et al*., 2007). During the 20th century, most of Europe experienced increases in average annual surface temperature (average increase 0.8°C), with more warming in winter than in summer (Alcamo *et al.*, 2007).

2.1.2. Projected regional changes for Europe

Landmasses are expected to warm more than the oceans, and northern, middle and high latitudes more than the tropics (Giorgi, 2006; Stendel *et al*., 2008; Kitoh and Mukano, 2009; Lean and Rind, 2009). Despite possible reductions in average summer precipitation over much of Europe, precipitation amounts exceeding the 95th percentile are very likely in many areas, thus episodes of severe flooding may become more frequent despite the general trend towards drier summer conditions (Christensen, 2004; Pal *et al*., 2004; Frei *et al*., 2006).

In an ensemble-based approach using outputs from 20 global climate models (GCMs), the Mediterranean, northeast and northwest Europe are identified as warming hot spots (Giorgi, 2006), but with regional and seasonal variations in the pattern and amplitude of warming (Giorgi and Lionello, 2008; Faggian and Giorgi, 2009; Brankovic *et al*., 2010). Regional climate models (RCMs) also project rising temperatures for Europe until the end of the 21st century, with an accelerated increase in the second half of the century.

For precipitation, the larger-scale summer pattern shows a gradient from increases in Northern Scandinavia to decreases in the Mediterranean region (Frei *et al*., 2006; Schmidli *et al*., 2007). By contrast, increases in wintertime precipitation primarily north of 45°N are a consistent feature of RCM projections over Europe, with decreases over the Mediterranean (Frei *et al*., 2006; Schmidli *et al*., 2007; Haugen and Iversen, 2008). Overall, then, there are consistent projections of change for northern and northwest Europe.

2.1.3. Climate change projections for Ireland

Mean seasonal temperature will change across Ireland. A number of studies have applied selected IPCC Special Reports on Emissions Scenarios (SRESs) (Nakicenovic *et al.*, 2000) to model climatic changes across Ireland at a regional scale. Despite the different methods (Hulme *et al*., 2002; Sweeney and Fealy, 2003; Fealy and Sweeney, 2007; McGrath and Lynch, 2008) and scenario combinations used, there is agreement in projected changes in temperature for Ireland. However, there are more disparities in the magnitude and sign for the precipitation changes projected for the island.

3. Policy implications for vulnerability and adaptation

3.1. European policy drivers

In 2009, the European Commission adopted a White Paper on 'Adapting to climate change: Towards a European framework for action'. This lays out a broad framework for action along four pillars: (1) increasing knowledge; (2) integrating adaptation into policy; (3) policy instruments; and (4) international cooperation (EC, 2009). European countries vary widely with respect to the state of their National Adaptation Strategies (NASs). However, within the terms of the EU communication there is a desire to build a specific 'framework to reduce the EU's vulnerability to the impact of climate change', although there is a reminder that the EU framework only complements the actions of Member States and wider international efforts (EC, 2009). The stage of NAS development depends on the magnitude and nature of the observed impacts, assessments of current and future vulnerability and the capacity to adapt. All countries have also submitted information on their adaptation plans in their 5th National Communication to the United Nations Framework Convention on Climate Change; this includes a submission for Ireland in February 2010 (DEHLG, 2010). Where the vulnerability assessment sits conceptually in a generic adaptation strategy roadmap is illustrated for further guidance and clarification (Figure 1).

European Environment: State and Outlook 2010 on Adapting to Climate Change' (EEA 2010a) describes European vulnerabilities to climate change under seven headings:

(1) Inland waters (glaciers and headwaters; river floods; drought and agriculture; water scarcity);
(2) Coastal zones (sea level rise; coastal flooding due to extreme events);

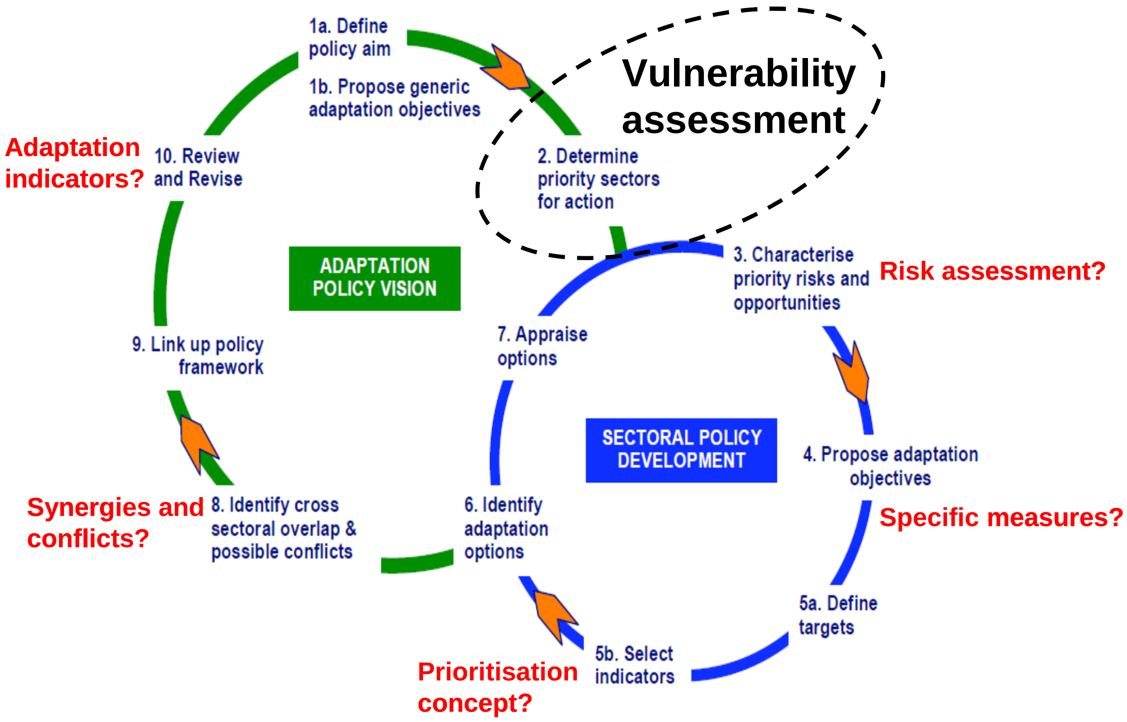

Figure 1: Vulnerability assessment located in a modified and annotated generic method for adaptation policy setting (Source: modified from Defra, 2005).

(3) Terrestrial biodiversity and ecosystems (wildlife and nature conservation);
(4) Economic sectors (agriculture and forestry; energy; tourism and recreation);
(5) Cities and the built environment (situation and urban design);
(6) Human health (heat stress; disease spread);
(7) Damage costs (economic losses from weather- and climate-related events).

As would be expected for any Member State, the analysis undertaken here for Ireland examines a number of vulnerabilities across the sectors, which largely parallel these broad headings.

3.2. Ireland's policy response

There is scientific consensus that the climate is changing, including that of Ireland, and more changes are projected for the coming decades. There is also an economic consensus that the costs of inaction will greatly outweigh the costs of action (Stern, 2006), and that progressive climate change policies, based on innovation and investment in low-carbon technology, are consistent with global economic growth (NCCS, 2007). However, future projections of climate change are subject to a high degree of uncertainty. As a result, climate change has several features that are distinct from the risk–hazards approach to other vulnerability assessments, primarily defining vulnerability with reference to a slowly evolving and partly uncertain future hazard.

The challenge for policy-makers is to implement robust adaptation options when surrounded by uncertainties; particularly when planning decisions also have to combine future economic and social projections of change. Therefore, in order to inform robust adaptation options, applying a range of climate projections derived from a range of emission scenarios and GCMs can take more account of the inherent uncertainty in climate change analysis. This has resulted in a growing awareness that adaptation to climate change needs an integrated approach involving all stakeholders on all institutional levels. This recognition has triggered work on the formulation of a coordinated national adaptation strategy as an important part of Ireland's response to climate change, alongside reducing greenhouse gas emissions. This recognises that Ireland will not be immune from the consequences of climate change; both the direct impacts in Ireland and the indirect impacts in other parts of the world.

Overall, therefore, the government is obliged to acquire more insight into the vulnerability of the country to climate change. This has to include shorter and longer term views of how to reduce vulnerability by implementing structural measures and spatial development options alongside sector-specific measures and possible technological innovation. However, the current lack of widespread climate adaptation measures leaves Ireland not only with a residual climate vulnerability, but also with a number of challenges related to current government structures to overcome (McGloughlin and Sweeney, 2012). This reflects the situation more widely across the European policy map. Therefore, perhaps more important than integrating climate policy more deeply into policy strategies is ensuring that it is extended more fully to specific policy instruments, including the adoption of new policy instruments (Mickwitz *et al*., 2009).

The results of the National Adaptive Capacity (NAC) assessment indicate that Ireland is in the early stages of the adaptation process. The most effective strategy for adaptation planning is to integrate climate change adaptation into policies, plans, programmes and projects at all levels of government and across all sectors (Shine and Desmond, 2011). The scope for integration of these into general and sectoral policies has been comprehensively reviewed and the need for an assessment and prioritisation of adaptation actions at the national level identified (Shine and Desmond, 2011).

3.3. Adaptation strategies: the state of play elsewhere in Europe

Complex combinations of issues drive countries to develop climate change adaptation strategies, of which a vulnerability assessment is an integral part. Consequently it is impossible to separate them out and identify a single key factor as they all play a role in most countries, but with different weights (Swart *et al*., 2009). Drivers include e.g. international climate negotiations, EU policies, experience of extreme weather events, examples of adaptation actions in other countries, research on impacts and adaptation, assessment of the economic costs of inaction or recognition of the opportunities presented by climate change (Swart *et al*., 2009).

The individual countries' NASs vary according to both the extent and the emphasis attached to the above vulnerabilities, and assignations are influenced by the potential impacts. For example, water stress is a concern in Southern European countries, and flood risk a concern of many central and northern European countries (Swart *et al*., 2009). The European Environment State and Outlook 2010 (EEA 2010b) describes adaptation measures as including 'technological solutions ("grey" measures); ecosystem-based adaptation options ("green" measures); and behavioural, managerial and policy approaches ("soft" measures)'.

Overall, then, European Economic Area member states are at different stages of preparing, developing and implementing their NASs. Updates for individual member states are available at: http://climate-adapt.eea.europa.eu/

4. Methodology

4.1. Assessment methodology summary

A cross-sectoral scope with the impact categories methodically defined for each sector was undertaken. Essentially this synthesised elements of the information on impacts available in the reports by Kerr *et al*. (1999), Sweeney *et al*. (2003), and Arkell *et al*., 2007. The approach also incorporated some of the elements advocated by, for example, Defra (2011). However, a further tier of information was added from the synthesis provided by the EPA (2009) for Ireland. Original information on seasonal dimensions of the likely impacts was also added, and based on this the impacts were systematically organised on a sector-by-sector basis.

To allow for a component of science uncertainty, a likelihood scoring element was applied to each identified impact based on the associated driving climatic variable. Temperature, for example, was scored at 3 on this scale to reflect the higher scientific confidence in the projected changes. The assigned score for temperature reflects a synthesis of views across the Irish impacts and modelling community (EPA, 2009); as well as a wider scientific consensus elsewhere across the literature (e.g. Coll *et al*., 2005, 2010; Coll 2010; Fowler *et al*., 2007; Hulme *et al*., 2002; Jones and Moberg, 2003), whereas impacts related to precipitation changes were scored at 2 and impacts related to sea-level or storminess changes were scored at 1 to reflect diminishing scientific confidence in the projected changes (e.g. Woolf & Coll, 2006/2007; Woolf & Wolf, 2010; Coll *et al*., 2013). For each sector the range of impacts were assigned a score based on an interpretation of whether the impact was deemed to be major or minor for the sector concerned, and a simple multiplication of this by the likelihood score was used to assign the initial (pre-adaptation) sensitivity. Space restraints due to the figure layout style used in the report here mean that not all the impacts can be represented.

4.2. Conceptual framework

Vulnerability assessment is a key aspect of anchoring assessments of climate change impacts to present development planning. Methods of vulnerability assessment have been developed over the past several decades in natural hazards, food security, poverty analysis, sustainable livelihoods and related fields. These approaches provide a core set of best practices for use in studies of climate change vulnerability and adaptation. When undertaking a vulnerability assessment for natural systems, the resilience or amount of change a system can undergo without changing state has to be assessed, although when referring to human systems, 'resilience' is frequently considered a synonym for adaptive capacity (e.g. White *et al*., 2001).

The inter-relationships between the terms and their conceptualisations are summarised in Figure 2, and show that, for example, in this simple conceptualisation, vulnerability can in part be framed as a function of resilience. Future vulnerability is related to the changed frequency of threshold exceedance under climate change, i.e. over long-term planning horizons. The development of increased adaptive capacity to cope with future climate will therefore be informed by the risk of threshold exceedance over the long term, but will build on adaptive strategies developed to cope with current climate.

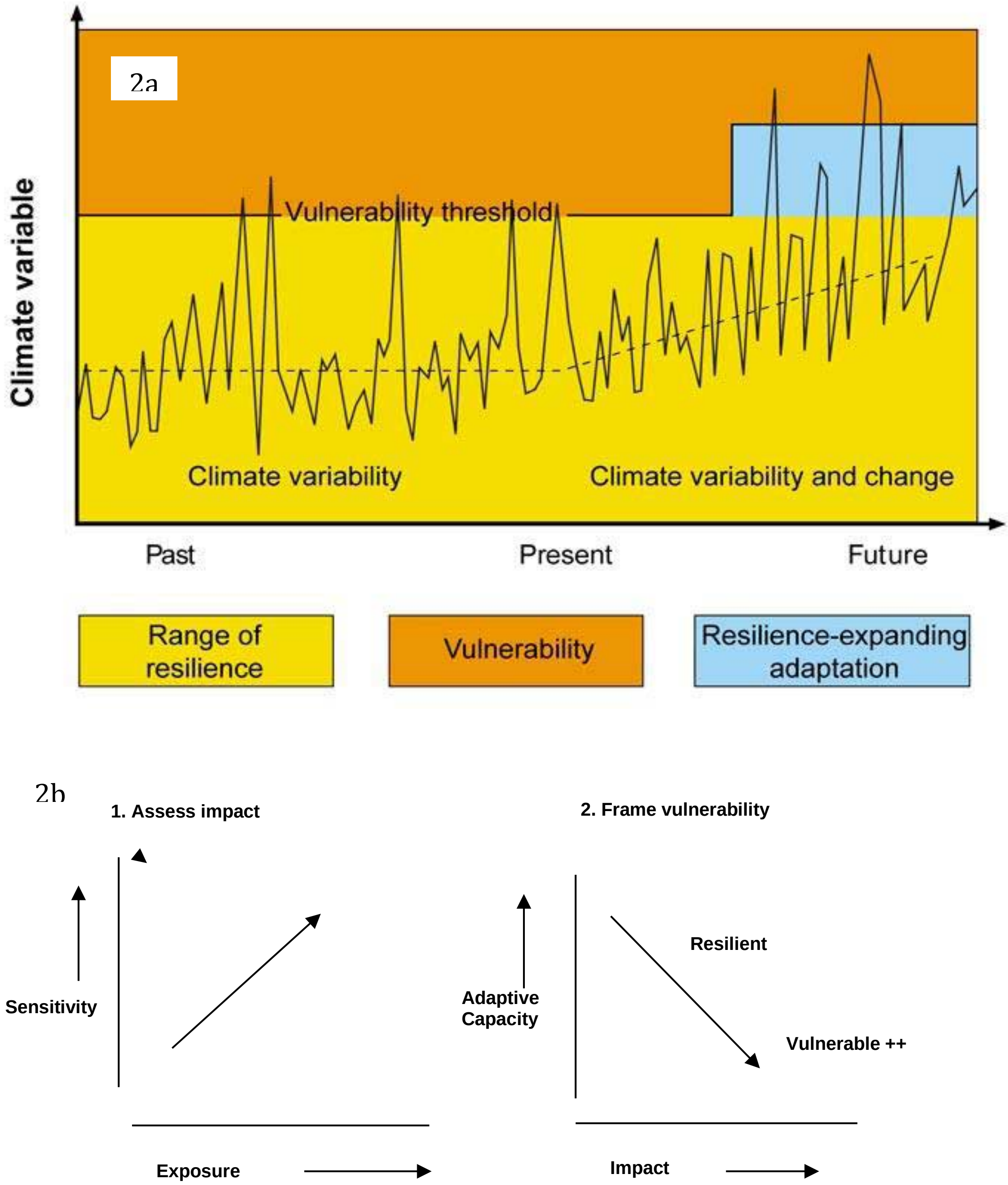

Figure 2a: Adaptation reduces vulnerability and increases resilience (Source: modified from Willows and Connell, 2003). 2b: Conceptualisation of the relationships and terms; linear relationships are not assumed, they are merely representative of concepts here.

4.3. Definitions and terms of reference

Climate change vulnerability must be distinguished from the assessment of impact of climate hazards, even if climate hazards are a part of climate change; in the natural hazards field there tends to be a focus on risk. By contrast, in the social sciences and in the dimensions of climate change, scientists prefer to talk in terms of vulnerability (Allen, 2003). The broadest definitions of vulnerability consider it to be a function of exposure, sensitivity and coping capacity; see e.g. Birkmann (2006), who examines more than 25 different definitions, concepts and methods to systematise vulnerability. Nevertheless, in assessing vulnerability to climate change, communities, organisations and other stakeholder groups are generally seeking information on two overarching questions:

1. How will specific systems, sectors or populations be affected by the impacts of climate change?
2. How do non-climate factors such as demographic trends, social and economic welfare, or community cohesion influence a society's ability to cope with or respond to those impacts?

Vulnerability can therefore be described as a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (EEA, 2008) (Figure 3). While vulnerability can be considered exclusively from a biophysical perspective or from a social one, these aspects need to be assessed together to reflect human capacity to cope with the biophysical impacts of vulnerability, an initial prioritisation of critical areas for a fuller climate change risk assessment and subsequent adaptation actions are the goal of this project.

Vulnerability to climate change refers to the propensity of human and ecological systems to suffer harm and their ability to respond to stresses imposed as a result of climate change effects. (Adger *et al*., 2007; Schneider *et al*., 2007)

Vulnerability in this context is often referred to as having three components:

- *exposure* is the 'nature and degree to which a system is exposed to significant climatic variations' (exposure to climate factors);
- *sensitivity* is the 'degree to which a system is affected, either adversely or beneficially, by climate-related stimuli' (sensitivity to change); and
- *adaptive capacity* is the 'ability of a system to

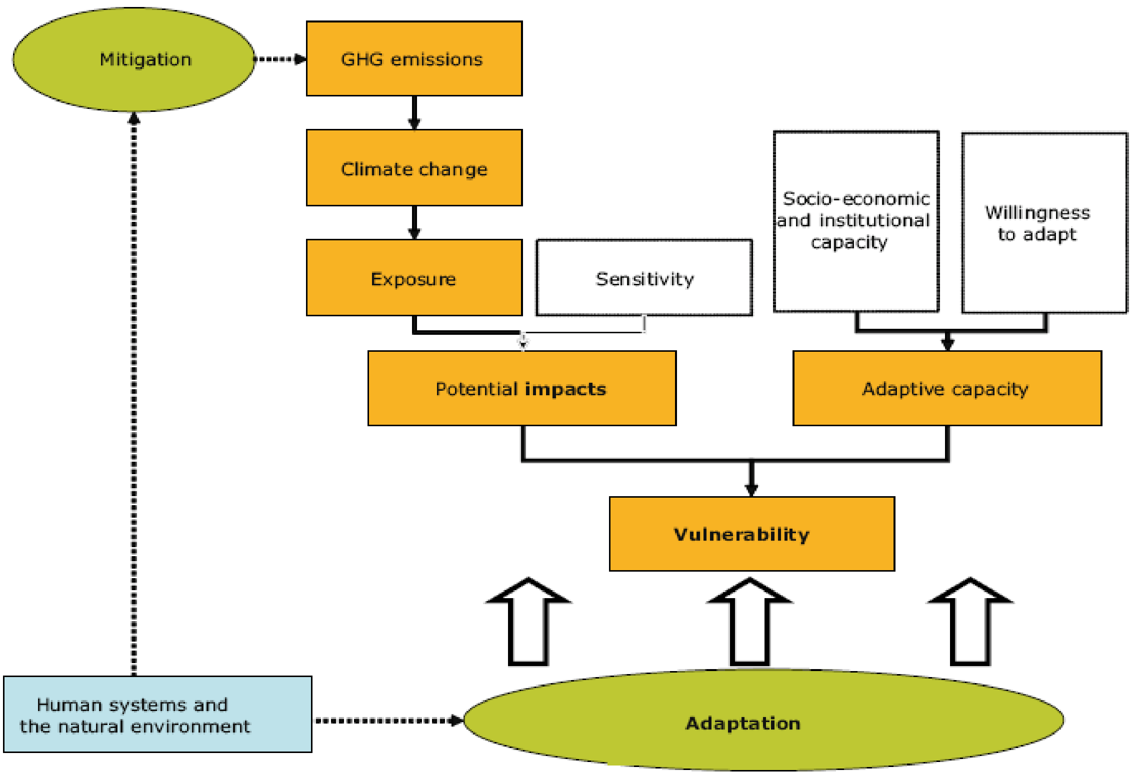

Figure 3: A conceptual model for climate change impacts, vulnerability and adaptation (Source: Isoard, 2010; IPCC, 2007; Füssel and Klein, 2006).

damages, to take advantage of opportunities, or to cope with the consequences'.

For the purposes of this document, sensitivity is interpreted as the degree to which a system will be affected by or responsive to climate stimuli, either positively or negatively. Within this scheme UNECE (2009), for example, considers the exposure as an external and the sensitivity and adaptive capacity as an internal dimension of vulnerability. Therefore, a highly vulnerable system is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to cope is limited (UNECE, 2009). This means that proactive adaptation policies should not be restricted to the analysis of the impact of climate change across different sectors, regions or social groups, but should encompass the assessment of their uneven adaptive capacity (EC, 2009), which will in part be a function of their sensitivity to the potential impact (Figure 3).

However, vulnerability assessments also include a subjective evaluation of the magnitude and distribution of projected effects as to their desirability and importance (Füssel and Klein, 2006). Whereas climate impacts can generally be described quantitatively by changes in biophysical indicators or in socio-economic indicators, there is no agreed metric to quantitatively describe the vulnerability of a natural system or sector. Consequently, it has been argued that vulnerability is a relative measure rather than something that can be expressed in absolute terms (e.g. Downing *et al*., 2001). The conceptual inclusiveness of vulnerability also implies that conducting a vulnerability assessment means that no element of the human–environment system may be simplified away or considered a mere boundary condition (Polsky *et al*., 2007).

A first-generation vulnerability assessment for Ireland

First-generation vulnerability assessments raise awareness of the (pre-adaptation) vulnerability of valued systems to climate change, and may also assess the relative importance of various climatic and non-climatic factors (Füssel and Klein, 2006). By doing so they help to prioritise further research and determine the need for mitigation and adaptation measures to reduce adverse effects of climate change, an outcome that may also be deduced from Figure 1. However, until the feasibility of implementing adaptations is assessed, an assessment cannot provide a full picture of the vulnerability for any given system.

Vulnerability assessment therefore can lead to the identification of 'no-regrets' measures to enhance adaptive capacity, but usually cannot provide justification for costly measures (Patt *et al*., 2005). Consequently, Patt *et al*. (2005) argue that the combination of climate change projections, socio-economic scenarios and estimates of adaptive capacity for a broad evaluation of vulnerability should actually be avoided, and that a more narrow focus on risks of particular communities could provide more meaningful results. Table 1 summarises the key components of such a first-generation assessment and characterises the features that distinguish this from a second-generation vulnerability or adaptation policy assessment.

Components	First generation vulnerability assessment	Second generation vulnerability assessment	Adaptation policy assessment
Main policy focus	Mitigation policy	International assistance	Adaptation Policy
Analytical approach	Mainly positive	Mainly positive	Normative
Main result	Pre-adaptation vulnerability	Post-adaptation vulnerability	Recommended adaptation strategy
Time horizon	Long-term	Mid- to long-term	Short- to long-term
Spatial scale	National to global	Local to global	Local to national
Consideration of climate variability, non-climatic factors, and adaptation	Partial	Full	Full
Consideration of uncertainty	Partial	Partial	Extensive
Integration of natural and social sciences	Low to medium	Medium to high	High
Degree of stakeholder involvement	Low	Medium	High
Illustrative research question	Which socio-economic impacts are likely to result from climate change?	What is the vulnerability to climate change, considering feasible adaptations?	Which adaptations are recommended for reducing vulnerability to climate change?

Table 1: Characteristic properties of three different stages of climate change vulnerability assessment (Source: modified from Füssel and Klein, 2006).

Though the severity of impacts will vary across Ireland, important sectors will be affected to a large extent. Therefore being clear on the framework applied and the terms of reference used is crucial. The lexicon of EU policy phrases the challenge as, for example, one of ensuring an 'optimal level of adaptation' (EC, 2009); however, no further insight is given as to the sense in which policy-makers should search for an optimum. For example, no guidance or indication is provided as to whether this follows a first- or second-generation vulnerability assessment within the Füssel and Klein (2006) framework laid out as a reference point here. Similarly, there is no indication of whether this should follow a full climate change risk assessment on a sector-by-sector basis supported by a new statutory instrument such as the Climate Change Bill, as is the case in the UK, for example.

However, the results of the NAC assessment indicate that Ireland is in the early stages of the adaptation process and emphasise the need for a vulnerability and risk assessment in order to prioritise and frame subsequent adaptation needs and options (Shine and Desmond, 2011). Support therefore is offered for the conceptual interpretation applied in this scoping exercise, i.e. to arrive at an assessment of first-generation vulnerability in order to prioritise subsequent actions.

Given the realities of working in a complex and highly uncertain setting, in elements of the methodology laid out here scoring criteria have been adjusted to reflect scientific confidence in projected changes to the climate variable of interest (Section 4.2). This also reflects the need for at least some partial consideration of uncertainty in a first-generation vulnerability assessment, which was identified within the Füssel and Klein terms of reference applied here. We recognise that Füssel and Klein frame this in terms of a mitigation policy focus and with a long-term horizon scan; nevertheless we adopt it here conditioned by our framing conceptualisation of vulnerability (Figure 2b). This is also in part pragmatic, since a full integration of natural and social sciences is beyond the resources and lifetime of the project remit here.

We also recognise that recently the emphasis has moved from better defining exposure and potential impacts to a better understanding of the factors that affect societies' sensitivity to those impacts and their capacity to adapt. This reflects the increasing recognition of the importance of considering social vulnerability alongside biophysical vulnerability. Various terms have been used to describe these different emphases, including biophysical versus social vulnerability, outcome versus contextual vulnerability (Eakin and Luers, 2006; Füssel and Klein, 2006; Eriksen and Kelly, 2007; Füssel, 2008, 2010) and scientific framing versus a human-security framing of vulnerability (O'Brien, 2006). O'Brien *et al.* (2007) argue that scientific and human-security frameworks affect the approach to adaptation, with the scientific framework leading to building local and sectoral capacity to make changes rather than address the fundamental causes of vulnerability, or climate change itself, within their broader geopolitical and economic contexts. O'Brien *et al.* (2007) also suggest that these interpretations are more succinctly summarized as 'outcome vulnerability', a linear result of the projected impacts; and 'contextual vulnerability', in a more holistic view of climate and society interactions.

It has also been suggested that a framework based on the concept of resilience is more appropriate than a vulnerability framework in many contexts. A resilience approach, for example, leads to more focus on interactions between social and biophysical systems (Nelson *et al*., 2007). However, the concept of resilience has proved very difficult to apply in practice, and is particularly resistant to attempts to establish commonly accepted sets of indicators. Some (e.g. Klein *et al*., 2003) have suggested that it has become an umbrella concept that has not been able to support planning or management effectively.

5. Identifying preliminary vulnerabilities for Ireland

5.1. Scoping across the sectors

By aggregating the impacts across some of the sectors examined here – for example, considering fisheries together with biodiversity, and including buildings, coastal and transport infrastructure as part of development infrastructure – the mutual interactions between climate change impacts and adaptation actions can be clustered out further to identify the areas of vulnerability (Figure 4). Some additional summary information is provided in Table 2, including a brief appraisal of the links between vulnerability and adaptation options for Ireland.

Based on a synthesis of current knowledge for Ireland, it is possible to identify some specific social, economic and environmental characteristics that could increase the country's vulnerability to a changing climate. At the same time, Ireland is well placed to take advantage of some of the opportunities that climate change may bring. These are summarised in Table 2.

			Climate change → (temperature, precipitation, air pressure)				
				Water - surface run-off - ground water - water quality - snow and ice	**Soil** - c-storage - fertility - erosion	**Air** - ozone - aerosols - particulate matter	**Biology** - phenology - migration
Sectoral adaptation strategies	**Adaptation measures**	Agriculture	•	•	•	•	•
		Forestry	•	•	•	•	•
		Energy	•	•			•
		Water	•	•	•	•	•
		Tourism	•	•		•	•
		Conservation	•	•	•	•	•
		Spatial development	•	•	•	•	•
		Health	•	•		•	•
		Natural hazards prevention	•	•	•		•

Figure 4: Interaction between climate change impact and adaptation measures by sector – • denotes a mutual interaction between climate change impact and adaptation measures. The large arrow is used to denote the changes to climate variables as the overarching driver for impacts across the sectors.

Table 2: Drivers affecting Ireland's vulnerability to and opportunities from climate change.

Demographics **Vulnerabilities:** • Densely populated urban areas, e.g. exposure to flooding and impacts from storm events. Dispersed rural areas and populations, e.g. exposure to transport disruption and interruption to energy and water supplies • Health challenges, which are more pronounced in areas of higher deprivation **Opportunities:** • Potential health benefits from higher winter temperatures and increased outdoor activity	**Economy** **Vulnerabilities:** • Some key growth sectors are intrinsically linked to climate and natural resources, e.g. food and drink, renewable energy, tourism • Vulnerable to effects of significant climate impacts in other countries due to a reliance on global export markets and supply chains **Opportunities:** • Some potential opportunities for tourism, agriculture and inward investment
Natural Resources **Vulnerabilities:** • Some species at the northern edge of their climatic range – loss of climate space • Large proportion of some natural resources concentrated in Ireland (peat bogs, wetlands, coastal machair) • Relatively high proportion of NW Europe soil carbon stocks are in Irish soils **Opportunities:** • New crops and fish species	**Infrastructure** **Vulnerabilities:** • Some transport and energy infrastructure networks are concentrated along corridors or coastal areas that are exposed to severe weather events • High carbon intensity of energy infrastructure

5.2. Impacts-based assessment ahead of the stakeholder input

Appendix 1 lays out a series of figures identifying a clustering of impacts and their importance in relation to an assessment of likely resilience by sector. This identifies where some of the key sensitivities lie, and is based on the scoring schema devised from the review of previous work outlined in Section 4.1. Accordingly, in this schema, weighing up sensitivity versus the impact can be also be interpreted as a 'best estimate' of first-generation (or pre-adaptation) vulnerability. In this case, the assessment methodology was akin to an impacts-first, science-first, or classical approach (IPCC, 2012; Figure 5).

An important caveat is that these only lay out current vulnerability and a provisional estimate of where future vulnerabilities may lie based on assessing present sensitivity/resilience in relation to the anticipated impacts. In reality, future vulnerability will evolve mediated by the system's adaptive capacity and the extent to which this capacity is realised as adaptation (Brooks, 2003).

By contrast, the approach adopted in seeking stakeholder input to the seminar can be broadly framed within a bottom-up vulnerability and thresholds-first approach (IPCC, 2012; Figure 5). However, the complexity and diversity of adaptation to climate change implies that there can be no single recommended approach for assessing, planning, and implementing adaptation options (Füssel, 2007; Hammill and Tanner, 2010; Lu, 2011). When the planning horizons are short and adaptation decisions impact only the next one or two decades, adaptation to

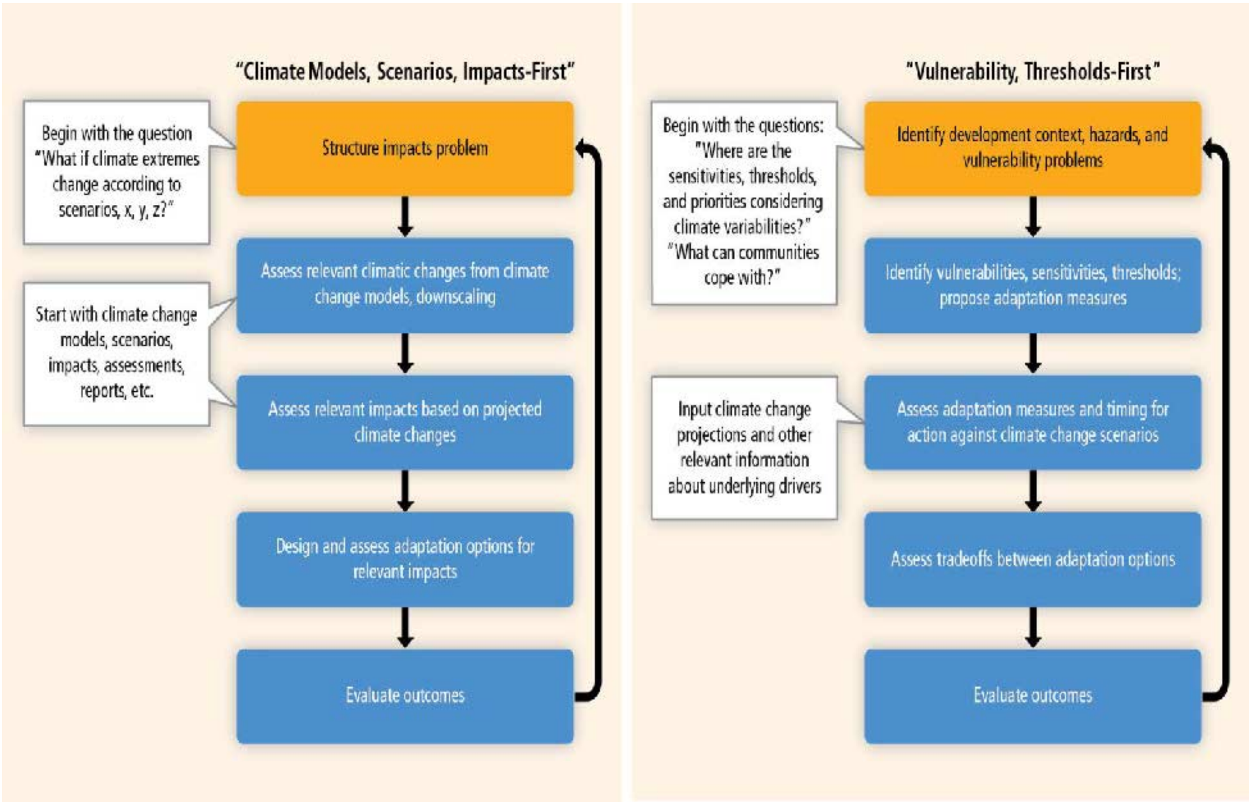

Figure 5 Top-down scenario, impacts-first approach (left panel) and bottom-up vulnerability, thresholds-first approach (right panel). A comparison of stages involved in identifying and evaluating adaptation options under changing climate conditions (Source: adapted from Kwadijk *et al.* (2010) and Ranger *et al.* (2010).

A preliminary set of adaptation actions can also be identified based on the impacts presented and the sensitivity and resilience of the relevant sector to these.

recent climate variability and observed trends may be sufficient (Hallegatte, 2009; Wilby and Dessai, 2010; Lu, 2011). For long-lasting risks and decisions, the timing and sequencing of adaptation options and incorporation of climate change scenarios become increasingly important (Hallegatte, 2009; OECD, 2009; Wilby and Dessai, 2010).

Figure 5 illustrates that gradations in options range from climate vulnerability or resilience approaches, sometimes described as 'bottom-up' (vulnerability, tipping point, critical threshold, or policy-first approaches), to climate modelling, impact-based approaches, sometimes described as 'top-down' (impacts-first, science-first or classical approaches) (IPCC, 2012). Although the bottom-up and top-down terms sometimes refer to scale, subject matter or policy (e.g. national versus local, physical to socio-economic systems), they are used here to describe the sequences or steps needed to develop adaptation policies at the national level (Lal *et al*., 2012). When dealing with long-term future climate change risks, the main differences between the scenarios/impacts-first and vulnerability-thresholds-first approaches lie in the timing or sequencing of the stages of the analyses (Kwadijk *et al*., 2010; Ranger *et al*., 2010) (Figure 5). Although this difference appears subtle, it has significant implications for the management of uncertainty, the timing of adaptation options, and the efficiency of the policymaking (Dessai and Hulme, 2007; Auld, 2008; Kwadijk *et al*., 2010; Wilby and Dessai, 2010; Lu, 2011).

For example, when the lifespan of a decision, policy or measure has implications for multiple decades or the decision is irreversible and sensitive to climate, the performance of adaptation and risk-reduction options across a range of climate change scenarios becomes critical (Auld, 2008; Kwadijk *et al*., 2010; Wilby and Dessai, 2010), whereas vulnerability thresholds-based approaches start at the level of the decision-maker and proceed to identify desired system objectives and constraints. They then consider how resilient or robust a system or sector is to changes in climate, assess the adaptive capacity and identify critical tipping points or threshold points. Arising from this, the viable adaptation strategies that would be required to improve resilience and robustness under future climate scenarios are identified (Auld, 2008; Urwin and Jordan, 2008; Hallegatte, 2009; Kwadijk *et al*., 2010; Mastrandrea et al., 2010; Wilby and Dessai, 2010). Therefore vulnerability thresholds approaches can be independent of any specific future climate condition (IPCC, 2012).

5.3. Rationale for the seminar exercises

In reassigning the summary of impacts in the tables provided on the day, contributors were asked to bear in mind two key points in relation to vulnerability and adaptation, and to reflect on some questions in relation to prospective vulnerability indicators (Annex 1). In addition the participants were supplied with the IPCC definitions of terms used to assign sensitivities prior to arriving at an assessment of adaptive capacity. These are provided in Annex 1.

In the seminar a modification of a deliberative risk-ranking methodology was applied: the Vulnerability Scoping Diagram (VSD) (Polsky *et al*., 2007), which allows rapid assessment and multiple stakeholder perspectives of vulnerability. This technique is based on methods of deliberative risk evaluation (Smith *et al*., 2000; Florig *et al*., 2001). The goal of the methodology is to engage stakeholders and sector practitioners collectively to provide qualitative contextual risk rankings as a first step in a vulnerability assessment. The importance of stakeholder engagement in vulnerability assessments has been highlighted in previous assessments and long-range hazard-planning efforts (e.g. Stern and Fineberg 1996; Wood *et al.,* 2002; Godschalk *et al.,* 2003; van Aalst *et al*., 2008; Frazier *et al*., 2010).

Stakeholder engagement is also seen as a significant element in Participatory Risk Mapping (PRM), a technique for engaging members of vulnerable communities to provide qualitative risk assessments (e.g. Smith *et al.,* 2000; Tschakert, 2007; López-Marrero and Yarnal, 2009). In addition, focus groups (or in this case sector practitioners with specialist knowledge) are effective for developing a deeper, more nuanced and more contextualized understanding of the kinds of value-based human dynamics involved in decision-making than the understanding resulting from quantitative models only (Moreno and Becken, 2009). By effectively hybridising the two approaches, the complementary techniques were used to arrive at a rapid subjective vulnerability assessment (but with the added value of expert input) across the sectors and within our conceptual first-generation assessment framework.

The report authors worked closely with EPA colleagues ahead of the seminar in order to try to secure a representative range of high-level expertise from within and between the sectors. On the day, the final participant mix was determined by the busy diaries of professional colleagues. Nevertheless, in the end sixteen stakeholders from across the sectors participated, and these were aided by three EPA colleagues as participant observers (Appendix 2).

6. Refining the assessment based on stakeholder input

6.1. Seminar assessment methods

6.1.1. Sensitivity assessment

In stage 1 the participants (a list of names and organisations is provided in Appendix 2) were presented with a range of climate stimuli and exposures for their respective sectors obtained from the same synthesis of sources as described in Section 4.2; and based on their insights and knowledge were asked to assign a sensitivity score. To aid this process and to stay within the terms of the original (EPA) specification for the project, the session facilitators provided a conceptual introduction to vulnerability and its components as per the IPCC definitions (Parry *et al.,* 2007). For each set of stimuli and exposure, the stakeholders were asked to assign a sensitivity ranging from low (1) to high (5) on the basis that this would allow some quantification of the sensitivities within and between the sectors.

6.1.2. Adaptive capacity assessment

Based on this assessment of exposure and sensitivity in stage 1, the interpretation was that the facilitators and stakeholders had moved to define the potential impacts as framed within the conceptual framework outlined in Figure 3. In order to move to an assessment of vulnerability within this framework, in stage 2 the facilitators again utilised the IPCC definitions to guide the participants to an assessment of adaptive capacity based on the potential impact assignations from stage 1. For each set of potential impacts, the stakeholders were asked to assign an adaptive capacity assessment ranging from low (1) to high (5). This was done on the basis that when the results from each stage were collated and assessed, a stakeholder-led assessment of vulnerability would be available within the conceptual framework outlined in Figure 3, and would also be informed by techniques for stakeholder engagement applied elsewhere.

6.2. Results

Following completion of the seminar, results for each assessment category across the sectors were collated. For both the sensitivity and adaptive capacity assessment, median-based scores were used on the basis that these would skew the results less than mean-based measures, particularly in cases where stakeholders had scored differently across the exposure unit and potential impact categories to assess sensitivity and adaptive capacity respectively.

Within the conceptual framework applied (Figure 3), the stakeholder assignation of vulnerability can be defined then as a combination of the sensitivity of the sector to the identified exposure units and the assessment of adaptive capacity to the potential impacts. In this respect the results provide information that moves them beyond a first-generation vulnerability assessment. In the assessment synthesis presented here, the stakeholders have used their expert knowledge of the sector to make a preliminary assessment of adaptive capacity. Therefore in the schema presented in Figures 6–14, it is the combination of the clustering of higher sensitivity to the exposure units assessed juxtaposed with a low adaptive capacity assessment to the potential impacts that would frame a sector as more vulnerable in the stakeholder-led assessment. In this sense, then, the figures provide some indication of the likely overall vulnerability since the expert insights of the stakeholders were already balancing the likely adaptation options against the potential exposure for each sector.

The figures are colour-ramped to aid visual interpretation of the stakeholder perception of vulnerability. Therefore, sectors assessed as more vulnerable will have more sensitivities assigned in the higher (red area) classes, alongside an overall adaptive capacity assigned to the lower (yellow area) classes. Conversely, sectors perceived as less vulnerable will have a more balanced assessment of sensitivity and adaptive capacity across the classes.

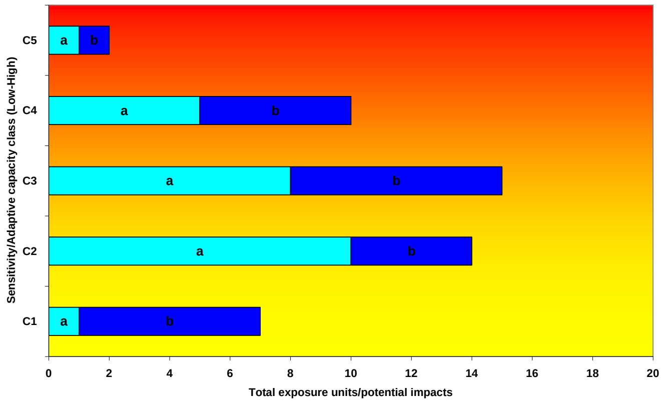

Figure 6: Summary of stakeholder seminar assessment of the distribution of sensitivity and adaptive capacity for the agriculture sector. (a) Stakeholder assignation of sensitivity class for exposures to all climate stimuli identified. (b) Stakeholder assignation of adaptive capacity class for all potential impacts identified. C1 denotes low and C5 high respectively. Median scores for the totals of each variable assigned to each class are presented.

Stakeholder perceptions for the agriculture sector assign most of the sensitivities to the intermediate categories for the exposures to the climate stimuli assessed, and this is more or less balanced by the adaptive capacity assessment in each category. Therefore, the stakeholder perspective indicates a potentially sensitive sector, but not one that is particularly vulnerable as the sensitivities are balanced by the potential capacity to adapt.

By contrast, the stakeholder assessment for the biodiversity sector clusters many of the sensitivities in the higher classes and these are offset by an overall low assessment for adaptive capacity. Overall, therefore, the assessment identifies a vulnerable sector.

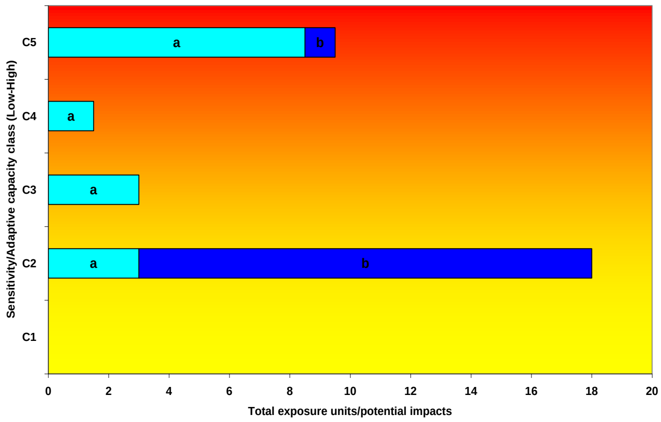

Figure 7: Summary of stakeholder seminar assessment of the distribution of sensitivity and adaptive capacity for the biodiversity sector. (a) Stakeholder assignation of sensitivity class for exposures to all climate stimuli identified. (b) Stakeholder assignation of adaptive capacity class for all potential impacts identified. C1 denotes low and C5 high. Median scores for the totals of each variable assigned to each class are presented.

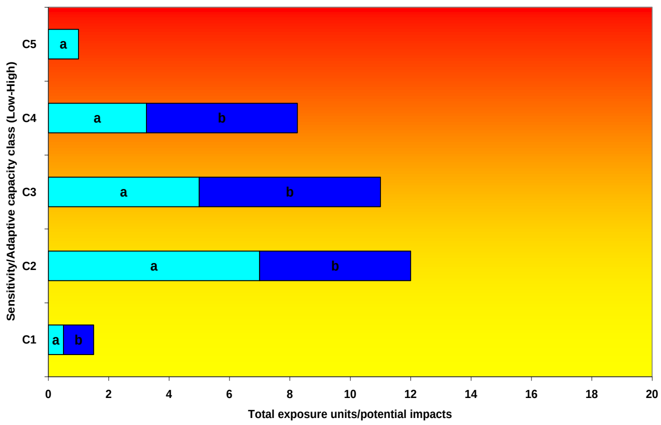

Figure 8: Summary of stakeholder seminar assessment of the distribution of sensitivity and adaptive capacity for the built environment sector. (a) Stakeholder assignation of sensitivity class for exposures to all climate stimuli identified. (b)

Stakeholder assignation of adaptive capacity class for all potential impacts identified. C1 denotes low and C5 high. Median scores for the totals of each variable assigned to each class are presented.

For the built environment sector, stakeholder perceptions identify most of the sensitivities as falling in intermediate to high classes. Again, however, these are largely offset by the assessment of adaptive capacity indicating a potentially vulnerable sector, but one where the sensitivities may be offset by the potential adaptation options.

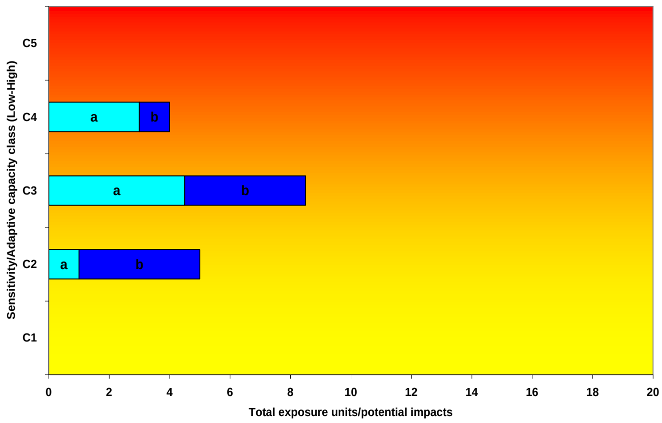

Figure 9: Summary of stakeholder seminar assessment of the distribution of sensitivity and adaptive capacity for the coastal sector. (a) Stakeholder assignation of sensitivity class for exposures to all climate stimuli identified. (b) Stakeholder assignation of adaptive capacity class for all potential impacts identified. C1 denotes low and C5 high. Median scores for the totals of each variable assigned to each class are presented.

Overall, the stakeholder assessment for the coastal sector (which included an assessment of the built infrastructure) indicates a potentially vulnerable sector. While, for example, the assessment of adaptive capacity more or less offsets sensitivities in the intermediate category, this is not reflected in the balance of the adaptive capacity assessment across the classes.

The stakeholder assessment of sensitivities for the energy sector assigned these as high. However, the sensitivities are offset by an assessment of high adaptive capacity for a sector not perceived as particularly vulnerable.

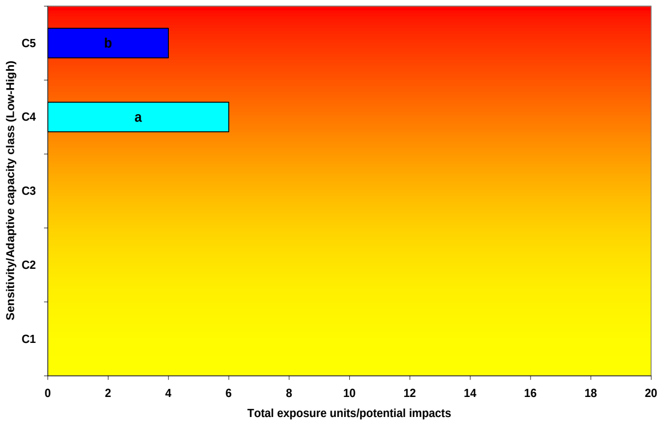

Figure 10: Summary of stakeholder seminar assessment of the distribution of sensitivity and adaptive capacity for the energy sector. (a) Stakeholder assignation of sensitivity class for exposures to all climate stimuli identified. (b) Stakeholder assignation of adaptive capacity class for all potential impacts identified. C1 denotes low and C5 high. Median scores for the totals of each variable assigned to each class are presented.

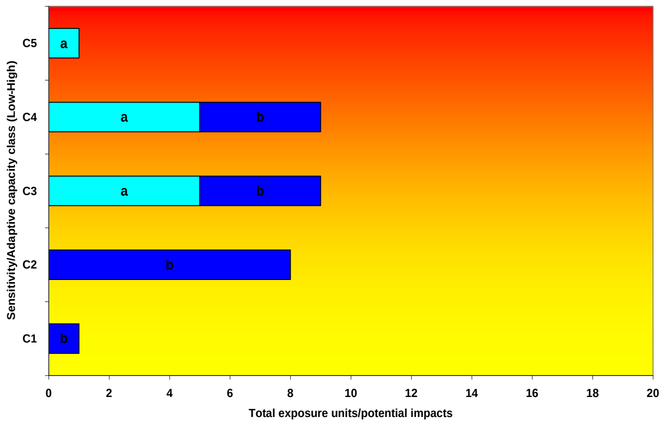

Figure 11: Summary of stakeholder seminar assessment of the distribution of sensitivity and adaptive capacity for the fisheries sector. (a) Stakeholder assignation of sensitivity class for exposures to all climate stimuli identified. (b) Stakeholder assignation of adaptive capacity class for all potential impacts identified. C1 denotes low and C5 high respectively. Median scores for the totals of each variable assigned to each class are presented.

The stakeholder assessment of the fisheries sector indicates a fairly vulnerable sector where the assignation of sensitivities to higher classes is not balanced by the assessment of adaptive capacity.

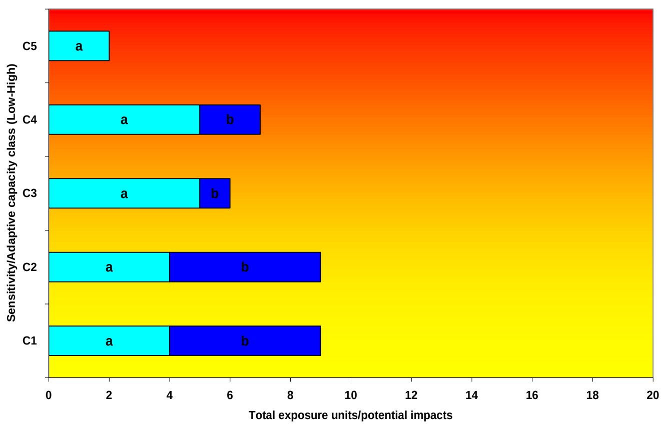

Figure 12: Summary of stakeholder seminar assessment of the distribution of sensitivity and adaptive capacity for the forestry sector. (a) Stakeholder assignation of sensitivity class for exposures to all climate stimuli identified. (b) Stakeholder assignation of adaptive capacity class for all potential impacts identified. C1 denotes low and C5 high. Median scores for the totals of each variable assigned to each class are presented.

The stakeholder assessment for the forestry sector is fairly mixed. Although, for example, the sector may be fairly balanced in terms of the adaptive capacity assessed for the sensitivities in the lower classes, this does not apply for the sensitivities assigned to the higher classes, indicating a potentially vulnerable sector to the exposures in these categories.

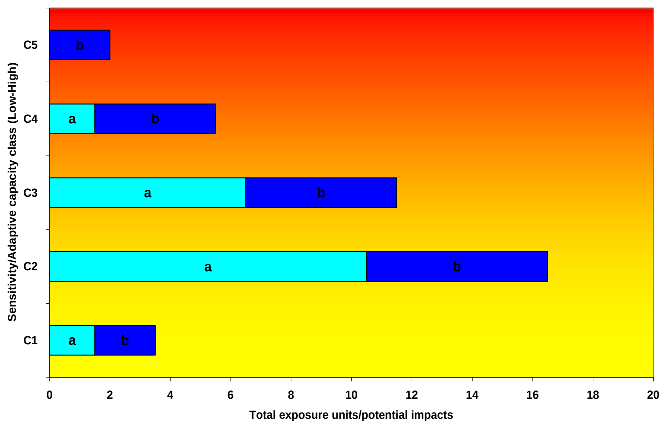

Figure 13: Summary of stakeholder seminar assessment of the distribution of sensitivity and adaptive capacity for the transport sector. (a) Stakeholder assignation of sensitivity class for exposures to all climate stimuli identified. (b) Stakeholder assignation of adaptive capacity class for all potential impacts identified. C1 denotes low and C5 high. Median scores for the totals of each variable assigned to each class are presented.

The stakeholder assessment for transport indicates a sector that may not be too vulnerable overall. For example, the sensitivity assessments in low to intermediate classes are offset by the adaptive capacity assessment, while in the higher categories the assessment of adaptive capacity is greater than the sensitivities assigned.

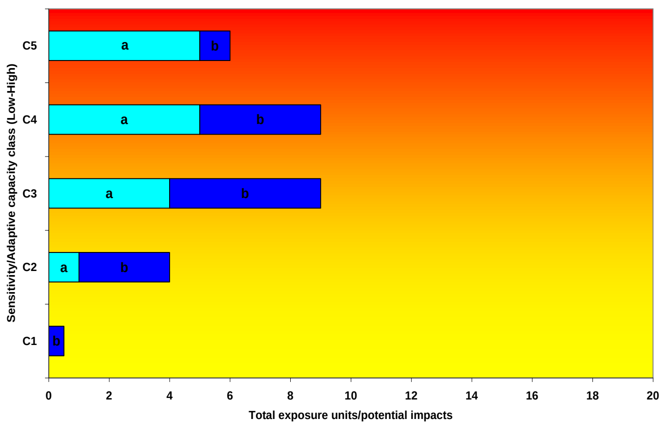

Figure 14: Summary of stakeholder seminar assessment of the distribution of sensitivity and adaptive capacity for the water sector. (a) Stakeholder assignation of sensitivity class for exposures to all climate stimuli identified. (b) Stakeholder assignation of adaptive capacity class for all potential impacts identified. C1 denotes low and C5 high. Median scores for the totals of each variable assigned to each class are presented.

The water sector assessment by the stakeholders again identifies a potentially vulnerable sector overall. Therefore, in the overall balance of the assessments between the classes, the adaptive capacity assessment does not balance the assessment of sensitivity for the climate stimuli identified.

Table 3: Summary of vulnerability by sector based on the stakeholder assessment

Sector	Sensitivity	Adaptive capacity	Vulnerability
Agriculture	Potentially sensitive	High	Not particularly vulnerable
Biodiversity	Highly sensitive	Low	Vulnerable
Built environment	Highly sensitive	Medium	Potentially vulnerable
Coastal	Sensitive	Low–Medium	Potentially vulnerable
Energy	Sensitive	High	Not particularly vulnerable
Fisheries	Highly sensitive	Low–Medium	Vulnerable
Forestry	Sensitive	Medium	Potentially vulnerable
Transport	Sensitive	Medium–High	Not particularly vulnerable
Water	Highly sensitive	Medium	Potentially vulnerable

6.3. The seminar assessment context and limitations

Vulnerability-threshold-based approaches start at the level of the decision-maker. They then identify desired system objectives and constraints, consider how resilient or robust a system or sector is to changes in climate, assess adaptive capacity and critical 'tipping points' or threshold points, and finally identify the viable adaptation strategies that would be required to improve resilience and robustness under future climate scenarios (Auld, 2008; Urwin and Jordan, 2008; Hallegatte, 2009; Kwadijk *et al*., 2010; Mastrandrea *et al*., 2010; Wilby and Dessai, 2010). While the seminar exercise here did not move beyond an initial assessment of adaptive capacity, nevertheless the exercise fell within the scope of a bottom-up vulnerability first approach, although no attempt was made to identify critical thresholds.

The approach is particularly useful for:

- identifying priority areas for action now,
- assessing the effectiveness of specific interventions when current climate-related risks are not satisfactorily controlled or when climatic

stress factors are closely intertwined with non-climatic factors,

- instances when planning horizons are short or resources are very limited (i.e. expertise, data, time and money), or when uncertainties about future climate impacts are very large (Agrawala and van Aalst, 2008; Hallegatte, 2009; Prabhakar *et al*., 2009; Wilby and Dessai, 2010).

However, vulnerability-thresholds-first approaches have been critiqued for the time required to complete a vulnerability assessment, for their reliance on experts, and for their largely qualitative results and limited comparability across regions (Patt *et al*., 2005; Kwadijk *et al*., 2010). Vulnerability-thresholds approaches can sometimes prove less suitable for guiding future adaptation decisions if coping thresholds change, or if climate change risks emerge that are outside the range of recent experiences (McGray *et al*., 2007; Agrawala and van Aalst, 2008; Auld, 2008; Hallegatte, 2009; Prabhakar *et al*., 2009; Wilby and Dessai, 2010).

Consequently, and as has been emphasised elsewhere in this assessment, climate change adaptation, including the assessment of vulnerability, must remain as an ongoing and iterative process. Therefore, as access to information is improved by better data and refined by better models, decision-making quality can be expected to improve steadily. In addition, the identification of critical thresholds (or adaptation tipping points) helps in answering the basic adaptation questions of decision- and policy-makers. These centre on: what are the first priority issues that need to be addressed as a result of increasing risks under climate change, and when might these critical thresholds be reached (Auld, 2008; Haasnoot *et al*., 2009; Kwadijk *et al*., 2010; Mastrandrea *et al*., 2010)? This integration also provides guidance on the sensitivity of sectors and durability of options under different climate change scenarios (Haasnoot *et al*., 2009; Kwadijk *et al*., 2010; Mastrandrea *et al*., 2010). Integrated approaches that link changes in climate variables to decisions and policies and express uncertainties in terms of timeframes over which a policy or plan may be effective (i.e. roughly when the critical threshold will be reached) also provide valuable information for plans and policies and their implementation (Haasnoot *et al*., 2009; Kwadijk *et al*., 2010; Mastrandrea *et al*., 2010).

6.4. Results comparison for the two approaches

It is increasingly recognised that the scenarios–impacts and vulnerability-thresholds approaches are complementary and need to be integrated, and that both can benefit from the addition of stakeholder and scientific input to determine critical thresholds for climate change vulnerabilities (Auld, 2008; Haasnoot *et al*., 2009; Kwadijk *et al*., 2010; Mastrandrea *et al*., 2010; Wilby and Dessai, 2010).

Although the assessment methodologies used here were variations on both approaches due to the scale of the resources available, the two exercises delivered broadly similar assessments for certain sectors, although differing markedly for others. In the impacts-led assessment, natural resources (biodiversity and fisheries) and the built infrastructure (including coastal areas) emerged as the most vulnerable sectors, followed by agriculture, water resources and forestry.

The stakeholder assessment also deemed biodiversity and fisheries to be the most vulnerable sectors, but delivered a more mixed assessment for agriculture and forestry, for example where they considered that the sensitivities were offset by the adaptive capacity. Water resources also emerged as potentially vulnerable in the stakeholder-led assessment, as did coastal resources. However, compared to the impacts-led approach, the stakeholder assessment for the built environment was more mixed, with an assessment that the sensitivities were again offset to some extent by the adaptive capacity.

The stakeholder-led assessment returned a substantially different assessment than the more impacts-based scoring for the synthesis of information on the exposures applied in the earlier assessment. In itself, the seminar was a unique attempt to elicit expert knowledge from across the sectors for Ireland, and to use this insight in a targeted fashion to arrive at a preliminary assessment of vulnerability within and between the sectors. In order to facilitate this and to stay within the original remit of the project, facilitators with a considerable depth of expert knowledge were used to help steer the participants and to frame the terms applied within the IPCC definitions. Therefore ahead of the stakeholder assessment, facilitator-led presentations carefully outlined the protocols that the workshop would follow and the conceptual framework that was being applied. These briefings elucidated the IPCC definitions supplied as part of Annex 1 here, and then expanded on these to show how the terminology would be used in the assessment framework. The objective, insofar as this was possible, was to apply the same definitions and assessment criteria clearly and unambiguously to each sector.

Another key finding of the work is that the terms used to frame vulnerability assessments and their consistent application are crucial. This in part reflects the recent shift in emphasis away from better defining exposure and potential impacts to attempting to take a more holistic view of the factors that affect societies' sensitivity to those impacts and the capacity to adapt. This includes the recognition of the importance of considering social vulnerability alongside biophysical vulnerability. Essentially this is a shift in conceptual thinking away from a top-down scenario and impacts-first approach to a bottom-up vulnerability and thresholds-first approach (IPCC, 2012).

7. Recommendations and conclusions

Within the conceptual framework applied, what is presented here is primarily a pre-adaptation assessment of vulnerability. Therefore, until the feasibility of implementing adaptation options is researched further based on a fuller assessment across natural and human systems, what is provided here cannot provide a full picture of the vulnerability for any given sector.

The emphasis on definitions in order to frame vulnerability is not simply one of academic nuance and debate presented within the framework here. If results here represent a preliminary first generation vulnerability assessment, albeit one strengthened by stakeholder input, what should follow is a full climate change risk assessment across the sectors to more fully inform a coherent national adaptation response.

For all the sectors, further research is required to identify critical thresholds or adaptation tipping points. These would help in answering the basic adaptation questions of decision- and policy-makers and help to frame new ones; for example, what are the first priority issues that need to be addressed as a result of increasing risks under climate change, and when might these critical thresholds be reached? Uncertainty about climate change is unlikely to be significantly reduced in the short term, but neither can a 'wait and see' strategy be adopted.

Therefore future research should encompass an integrated scenarios–impacts (top-down) and vulnerability-thresholds (bottom-up) approach, and would benefit from more stakeholder input and a greater scientific resource allocation to determine critical thresholds for climate change vulnerabilities within and between sectors. Rather than trying to predict impacts through individual scenarios, such an integrated approach would help identify the triggers, or critical thresholds, that signal a state of vulnerability for any given sector.

Throughout all cycles of policy implementation and review, the options for climate change adaptation including the assessment of vulnerability must remain part of an iterative process. Therefore, as access to information is improved by better data and refined by better models, decision-making quality can be expected to improve steadily. Arising from this, guiding principles for managing uncertainty and surprises include:

- Build in robust, flexible and reversible adaptation options;
- Incorporate 'no-regrets' options that provide benefits over a range of climates and without climate change;
- Incorporate waiting and learning approaches that build information before taking inflexible actions to arrive at 'no-regrets' outcomes;
- Evaluate sequencing strategies, e.g. adaptations to built infrastructure that can be modified in the future.

The caveats aside, based on the results from both the assessment methodologies used here, the priority sectors for further investigation are:

- Biodiversity and fisheries;
- Water resources and the built coastal environment;
- Forestry and agriculture.

Annex 1

1. Workshop questions and definitions provided for stakeholders in short briefing report

In reassigning the summary of impacts in the tables provided on the day, contributors were asked to bear in mind two key points in relation to vulnerability and adaptation, and to reflect on some questions in relation to prospective vulnerability indicators.

(i) Ireland's vulnerability to worst-case climate change scenarios is largely unknown

- The present state of the science means probabilities can't be assigned to unexpected changes; thus low probability/high impact climate 'surprises' cannot be ruled out. An obvious example of this would be a slowing or sudden shut down of the North Atlantic Thermohaline Circulation (THC) system in response to accelerated warming and freshwater inputs around high latitude regions adjacent to the Arctic.

(ii) A flexible, adaptive and iterative strategy is required due to uncertainties

- Behavioural adaptations and warning systems can be effected and implemented in the short term, whereas spatial structure adaptation and infrastructure developments require long lead times.

Questions to stakeholders regarding vulnerability indicators

Vulnerability is a relative measure and does not exist as something that can be observed and measured. Therefore, indicators can only be selected based on choices by the assessment team and stakeholders from the vulnerable sectors themselves. Developing and using indicators would require awareness of several issues, including for example their sensitivity to change, standardising indicators for comparison, reliability of the data, mapping of indicators, collinearity between indicators and coverage of relevant dimensions of vulnerability. However, these issues aside:

- How and for which purposes do you think that vulnerability indicators could be used for your sector?
- Do you see scope for where your existing structures and frameworks can be adapted to encompass vulnerability?
- How do you see the relationship between generic EU-wide indicators and location-specific characteristics of vulnerability indicators for sector-based application in Ireland (these could include e.g. thresholds for impacts)?

IPCC definitions of terms supplied to workshop participants

Exposure: The nature and degree to which a system is exposed to significant climatic variations (IPCC, 2007).

(Climate) Impacts: Consequences of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts.

- Potential impacts: All impacts that may occur given a projected change in climate, without considering adaptation.
- Residual impacts: The impacts of climate change that would occur after adaptation (IPCC, 2007).

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2007).

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea level rise) (IPCC, 2007).

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation (IPCC, 2007).

Adaptive capacity: The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007).

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Appendix 1: Pre-stakeholder workshop assignation of sensitivity by sector figures

Area of action: Natural resources and biodiversity

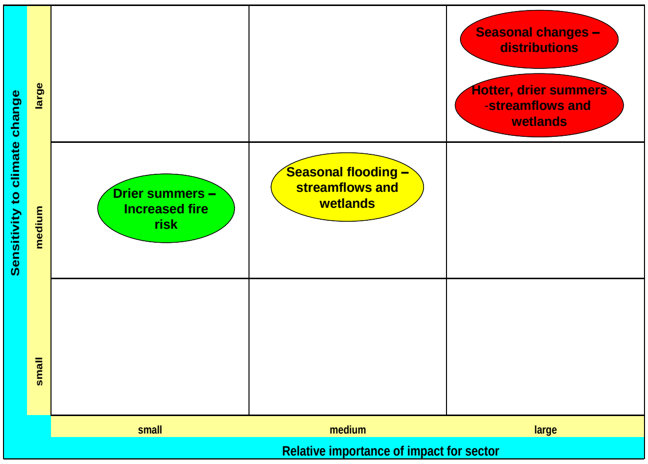


Figure A1: Impacts clustering for the natural resources and biodiversity sector. Red background denotes high sensitivity and may imply a high-priority adaptation action; yellow background denotes medium sensitivity and may imply a medium adaptation action priority; green background denotes low sensitivity and may imply a low-priority adaptation action or limited options. Sensitivity is interpreted as the degree to which a system will be affected by, or responsive to, climate stimuli, either positively or negatively (this also applies across subsequent sector figures).

Area of action: Fisheries

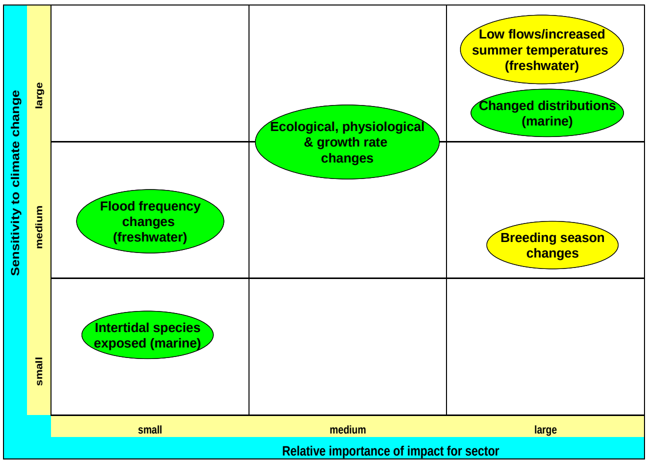
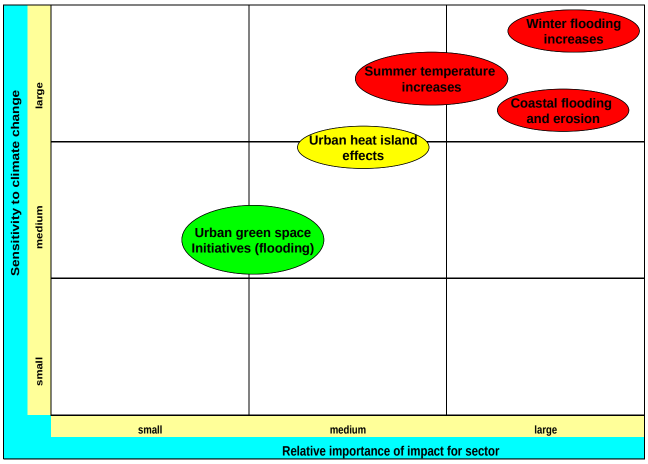


Figure A2: Impacts clustering for the fisheries sector.

Area of action: Built environment and coastal settlements



igure A3: Impacts clustering for the built environment and coastal settlements sector.

Area of action: Arable agriculture and animal health

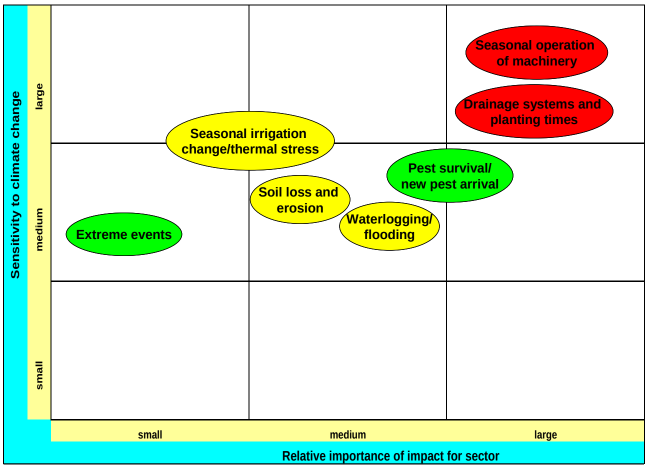


Figure A4: Impacts clustering for the agricultural sector.

Area of action: Water resources

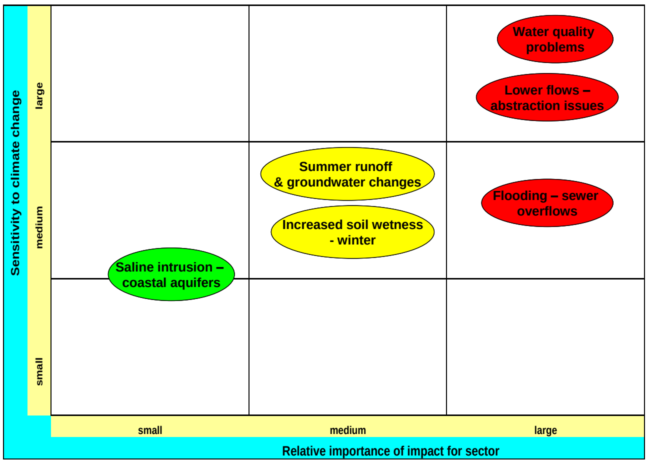


Figure A5: Impacts clustering for the water resources sector.

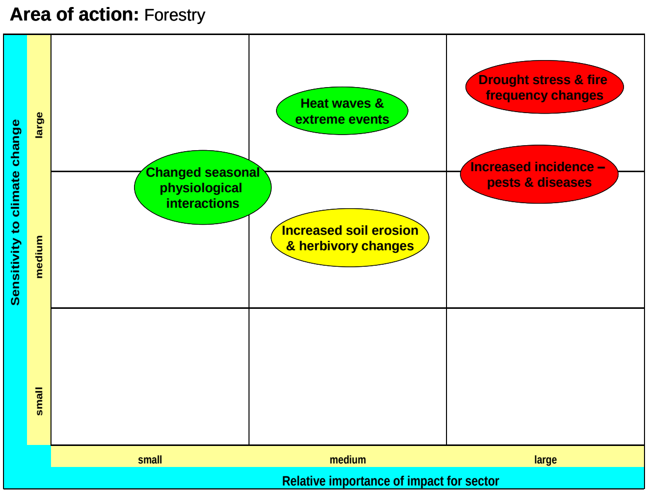


Figure A6: Impacts clustering for the forestry sector.

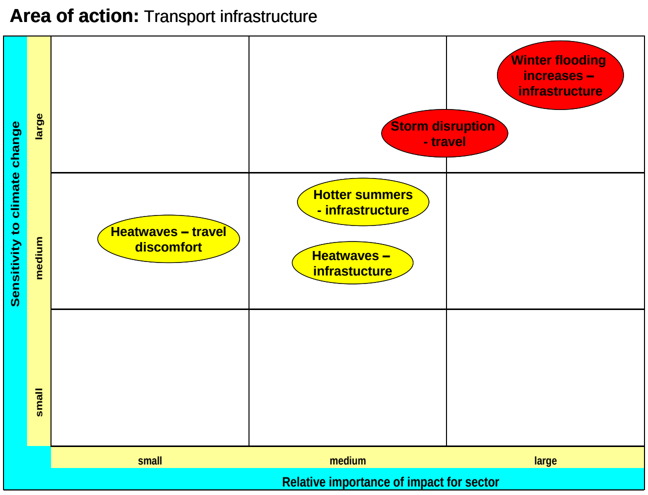


Figure A7: Impacts clustering for the transport sector.

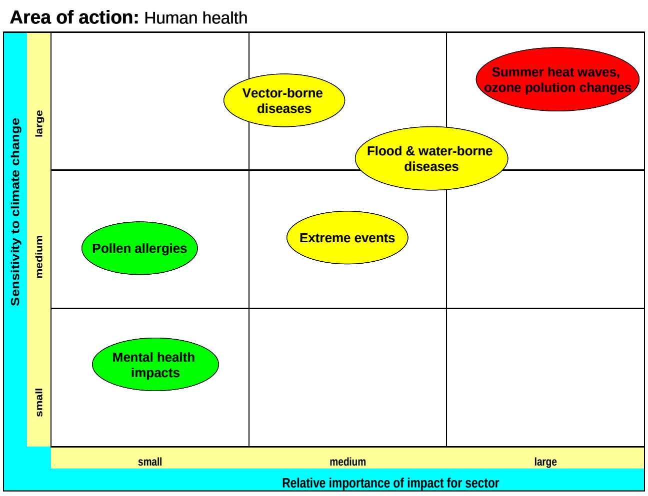


Figure A8: Impacts clustering for the human health sector.

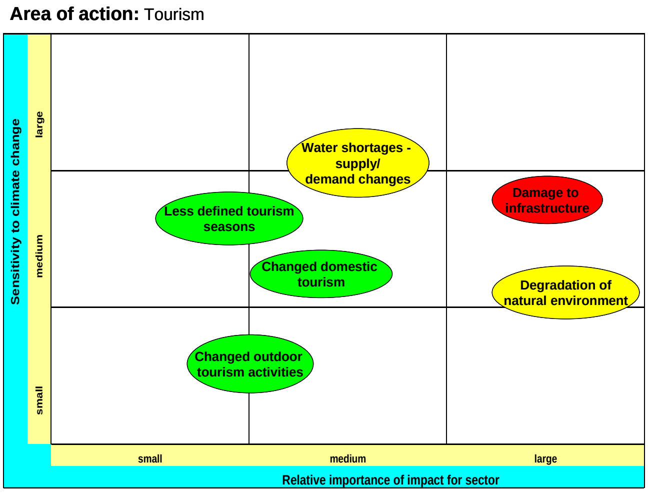


Figure A9: Impacts clustering for the tourism sector.

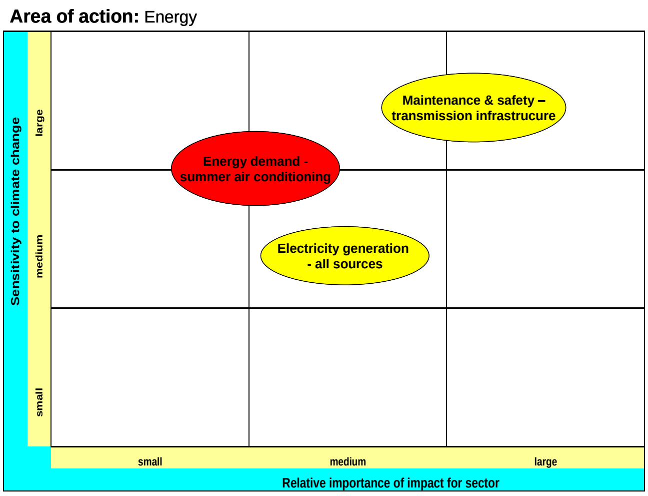


Figure A10: Impacts clustering for the energy sector.

Appendix 2: Participant list –

Consultation Seminar, John Hume Boardroom, NUI Maynooth, Wednesday 14 March 2012

Name & Organisation	Role
Caitriona Douglas, NPWS	Stakeholder
Noel Casserly, DECLG	Stakeholder
Yvonne Butler, DECLG	Stakeholder
Glenn Nolan, Marine Institute	Stakeholder
Jim Casey, OPW	Stakeholder
James Nix, Corporate Leadership	Stakeholder
Catherine Farrell, Bord na Mona	Stakeholder
John Hartnett, An Taisce	Stakeholder
Jane O'Keeffe, IMERC	Stakeholder
Donagh O'Mahony, ESB	Stakeholder
Gary Lanigan, Teagasc	Stakeholder
Kevin Black, FERs LTd	Stakeholder
Owen Lewis, SEI	Stakeholder
Karin Dubsky, Coastwatch	Stakeholder
Barry O'Dwyer	Observer/stakeholder
Maria Falaleeva	Observer/stakeholder
Frank McGovern, EPA	Observer
Margaret Desmond, EPA	Observer
Phillip O'Brien, EPA	Observer
John Sweeney, NUIM	Presenter/facilitator
John Coll, NUIM	Presenter/facilitator
David Smyth, NUIM	Facilitator
Jackie McGloughlin, NUIM	Facilitator

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce;
- dumpáil mara.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

Climate Change Research Programme (CCRP) 2007-2013

The EPA has taken a leading role in the development of the CCRP structure with the co-operation of key state agencies and government departments.
The programme is structured according to four linked thematic areas with a strong cross cutting emphasis.
Research being carried out ranges from fundamental process studies to the provision of high-level analysis of policy options.

For further information see
www.epa.ie/whatwedo/climate/climatechangeresearch

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An Ghníomhaireacht um Chaomhnú Comhshaoil

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Comhshaol, Pobal agus Rialtas Áitiúil
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