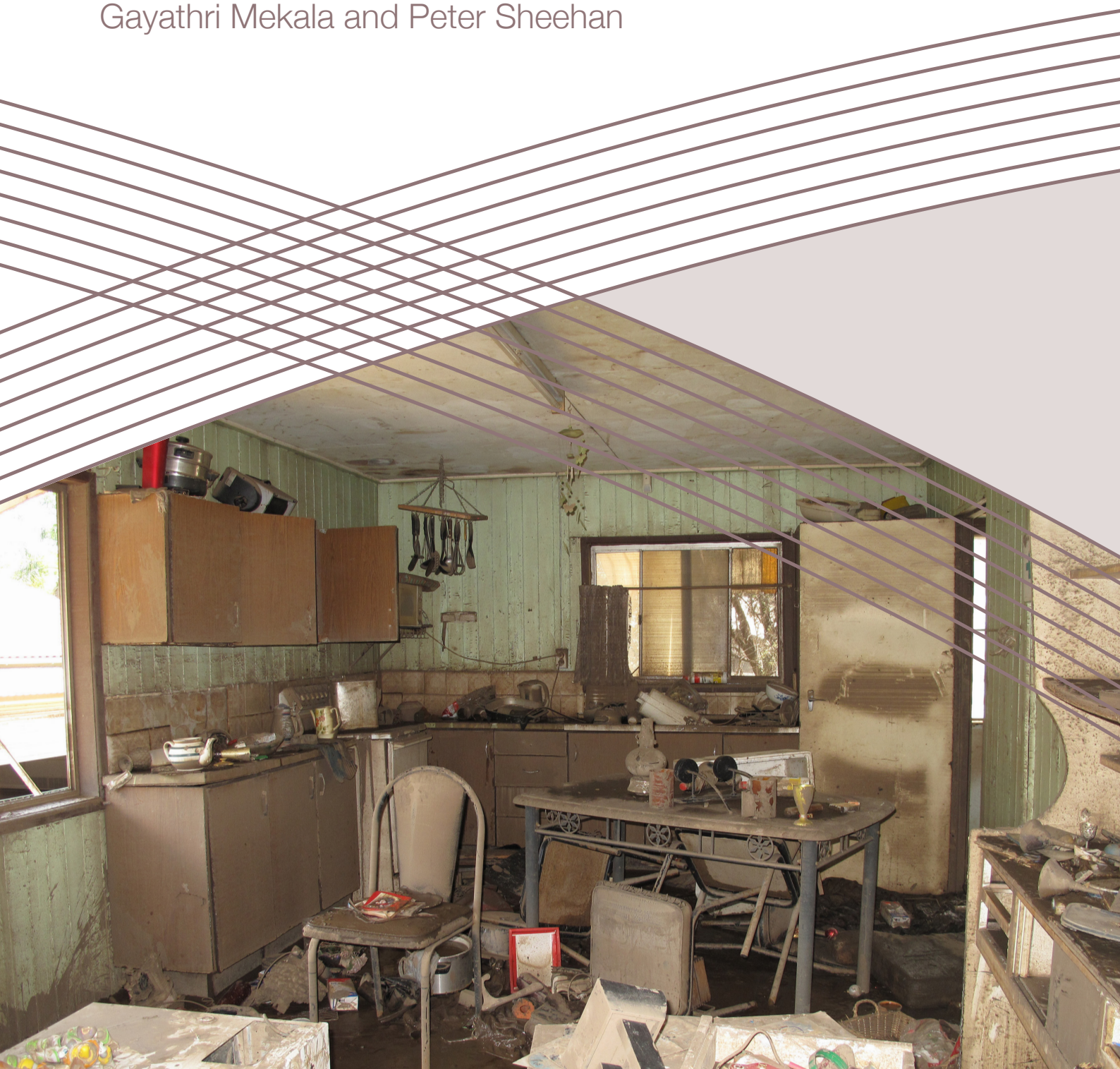


Valuing adaptation under rapid change

Final Report

Roger Jones, Celeste Young, John Handmer, Adriana Keating,
Gayathri Mekala and Peter Sheehan



VALUING ADAPTATION UNDER RAPID CHANGE

Anticipatory adjustments, maladaptation and transformation

Victoria University and RMIT University

AUTHORS

Roger N Jones

Celeste Young

John Handmer

Adriana Keating

Gayathri Mekala

Peter Sheehan



Published by the National Climate Change Adaptation Research Facility

ISBN: 978-1-925039-27-6
NCCARF Publication 56/13

© Victoria University 2013 and National Climate Change Adaptation Research Facility

This work is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without prior written permission from the copyright holder.

Please cite this report as:

Jones, RN, Young, CK, Handmer, J, Keating, A, Mekala, GD, Sheehan, P 2013
Valuing adaptation under rapid change, National Climate Change Adaptation Research Facility, Gold Coast, pp. 192.

Acknowledgement

This work was carried out with financial support from the Australian Government (Department of Climate Change and Energy Efficiency) and the National Climate Change Adaptation Research Facility (NCCARF). The Victorian Centre for Climate Change Adaptation Research is thanked for in-kind support of Celeste Young and for knowledge exchange.

The role of NCCARF is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government, business and in vulnerable sectors and communities to manage the risk of climate change impacts.

We would like to thank Roderick Marsh for workshop assistance and reviewing, Kate Lonsdale, Leon Soste and Geoffrey Williams for workshop assistance and Geoff Brown for workshop facilitation. Two anonymous reviewers are thanked for their comments.

Disclaimer

The views expressed herein are not necessarily the views of the Commonwealth or NCCARF, and neither the Commonwealth nor NCCARF accept responsibility for information or advice contained herein.

Cover images

Copyright bigstock.com

Table of contents

ABSTRACT	1
EXECUTIVE SUMMARY	2
1. OBJECTIVES OF THE RESEARCH	5
1.1 Background to the project	5
2. RESEARCH ACTIVITIES AND METHODS	8
2.1 Project design and methods	8
2.2 Report structure	9
2.3 Economic framework for adaptation	11
2.4 Institutional Analysis and Development framework	12
2.4.1 Action/adaptation situations	14
2.4.2 External variables	16
2.4.3 Interactions	17
2.4.4 Outcomes	18
2.5 Statistical analysis of climate change	18
3. RESULTS AND OUTPUTS	21
3.1 Understanding rapid climate change	21
3.1.1 Recent events and climate risks	21
3.1.2 The science of rapid climate change	24
3.1.3 The anatomy of rapid climate change	28
3.2 Gradualism: current approaches to assessment	34
3.2.1 Current narratives and their influences	34
3.2.2 Standard assessment methods and gradualist narratives	37
3.2.3 Orthodox economics of impacts and adaptation	39
3.2.4 Current policy overview	45
3.3 Economic responses to rapid change	51
3.3.1 Heat stress and transfer	51
3.3.2 Fire risk	54
3.3.3 Assessing risks and risk propagation	58
3.3.4 Adaptation clusters	62
3.3.5 Understanding the problem at the national scale	65
3.3.6 Key factors for assessing and valuing rapid change	67
3.4 Evaluating the solutions	75
3.4.1 Valuing adaptation	75

3.4.2	<i>Project workshop Beyond the Mean: synthesis and results</i>	76
3.4.3	<i>Evaluation criteria</i>	90
3.4.4	<i>Knowledge, innovation and transformation</i>	95
3.4.5	<i>Transformation</i>	103
3.4.6	<i>Maladaptation</i>	106
3.4.7	<i>Developing capacity</i>	108
3.4.8	<i>Policy implications of rapid change</i>	114
3.5	Implementation	126
3.5.1	<i>Question-based process for policy assessment</i>	126
3.5.2	<i>Application of economic tools</i>	130
4.	GAPS AND FUTURE RESEARCH DIRECTIONS	135
	GLOSSARY	139
	APPENDIX A: ORIGIN OF THE GRADUALISTIC SCIENTIFIC NARRATIVE	141
	APPENDIX B: THE PROBLEM-SOLUTION ADAPTATION IMPLEMENTATION	
	FRAMEWORK SUMMARY	153
	REFERENCES	157

List of figures

Figure 1. Economics and adaptation decision-making framework with a problem-solution focus (Adapted from Young, 2012, Appendix B).	11
Figure 2. A framework for institutional analysis (Ostrom, 2005, 2011).	12
Figure 3. Institutional framework for assessing the economics of adaptation (Based on Ostrom, 2011 and others).	14
Figure 4. Single climate model simulation for south-east Australian minimum temperature (CSIRO Mk3.5 A1B $T_{min_{AGW}}$) showing a) annual variability, and b) mean change for a high emissions pathway.	19
Figure 5. Maximum temperatures measured at Laverton Jan–Feb 2009 showing the heatwave (43.2°C, 44.8°C, and 44.8°C) and fire (Black Saturday; 47.5°C) peaks.	21
Figure 6. a) South-west WA rainfall 1900–2012, showing statistically significant step and trend profile (long dashes), 11-year running average (light grey) and linear trend (dotted); b) sea surface temperatures for Australia 1910–2011; c) maximum temperature for south-east Australia 1910–2011; and d) minimum temperature for south-east Australia 1910–2011.	23
Figure 7. Weather-related insurance claims for Victoria 1990–2011. Damages in millions of dollars on the left and as a percentage of gross state product on the right.	24
Figure 8. Single climate model simulation for south-east Australian minimum temperature (CSIRO Mk3.5 A1B $T_{min_{AGW}}$) showing a) the mean, b) annual variability and c) mean, annual variability and step changes for a high emissions pathway.	25
Figure 9. Selected local, regional and global climate variables covering air and sea surface temperature, ocean heat content and tide gauge records. Statistically significant step changes to the 1% and 5% level analysed with the bivariate test (left) and STARS test (right) are shown with year and size of change between periods. Method of analysis described in Jones (2012). ..	26
Figure 10. Coping range showing (a) the relationship between climate change and threshold exceedance, and (b) how adaptation can establish a new critical threshold, reducing vulnerability to climate change (Jones and Mearns, 2005).	30
Figure 11. Frequency distribution of a) daily and b) monthly temperature at Laverton for the period 1944–1972, 1973–1996 and 1997–2011. Number of days c) from 35–40°C and >40°C 1944–2011 with the average of days above 35°C shown as black lines before after 1997; and d) scaled as a function of temperature from a baseline of 1974–1996, shown with the 1997–2011 average from c. Note that the averages from the periods 1944–1996 and (c) 1974–1996 (d) are slightly different.	32
Figure 12. Conceptual model of the development of expert knowledge and narratives informing adaptation.	35
Figure 13. A comparison of the modelled expected market costs for Australia of unmitigated and mitigated climate change up to 2100 (Garnaut, 2008).	45
Figure 14a) Simulated heat deaths for Melbourne using a single climate model simulation showing statistically significant step changes in death rates with constant 2011 population; b) heat deaths for Melbourne with population increasing according to recent estimates from the Victorian Department of Human Services and the ABS; and c) as for b) with population increase in 65 and older group.	52
Figure 15. Annual total value of a statistical life (VSL) for Melbourne, based on rate of change of the population 65 and over and change in maximum temperature from the CSIRO Mk3.5 A1B simulation, represented as individual year averages for Oct–Mar and the accrued differences between the two in \$million AUD2011 for a) zero discount rate, b) 2.5% discount rate, and c) 5% discount rate.	53
Figure 16. Estimated changes in days of high to catastrophic fire danger based single model run of annual maximum temperature and total rainfall from a grid square over Melbourne from the CSIRO Mark3.5 A1B model, based on Laverton data.	56

Figure 17. Average number of days of high to catastrophic fire danger days per year from nine Victorian stations, adjusted for inhomogeneities in wind speed. Original data from Lucas (2009).	56
Figure 18. Average number of days of extreme–catastrophic fire danger for Victoria derived from maximum temperature and rainfall from the CSIRO Mk3.5 A1B simulation. a) Data represented for fire years, showing output (red line), trends (brown dashed line), separated by a step change (2057), along with a simple trend (dotted red line). Annual loss and accrued difference between the raw data and trend line in \$million AUD2011 for b) zero discount rate, b) 2.5% discount rate, and d) 5% discount rate.	57
Figure 19. Schematic representation of spatial and government domains with some extreme events likely to cross domains either singly or in succession.	59
Figure 20. National summary of adaptation clusters according to a) gross income 2005–06, and b) sensitivity as a proportion of income.	65
Figure 21. Integrated natural hazards map of Australia developed from past hazard vulnerability (30%) and hazard potential (70%) (Blong, 2005).	66
Figure 22. Allocation of time scales to 176 primary impacts.	85
Figure 23. Breakdown of multiple time scales to 30 lasting impacts.	85
Figure 24. Assigned domains to a total of 176 impacts.	86
Figure 25. Number of domains assigned to a single impact.	86
Figure 26. Adaptation clusters assigned to impacts across the six workshop groups.	87
Figure 27. Adapted from adopter categorization on the basis of innovativeness (Rogers, 2003).	96
Figure 28. Key innovation needs (C. Young).	99
Figure 29. The linear technology-transfer view of how K* would link research to policy and practice (Shaxson et al., 2012).	100
Figure 30. Adaptation knowledge framework (Young, 2013).	101
Figure 31. Schematic of temperature frequency about the mean showing a shift to warmer conditions with a greatly increased exceedance of extreme heat events.	116
Figure 32. Scenario map showing sensitivity of the governments and financial markets. Each quadrant corresponds to one of the four scenarios (Jones et al., 2013).	122
Figure 33. Diagram of risk propagation across domains showing the need for adaptive response following the direction of risk and the need for resources to meet increased demand for adaptation.	123
Figure 34. Problem/solution uncertainty matrix with economic strategies.	131
Figure 35. Single climate model simulation for south-east Australian minimum temperature (CSIRO Mk3.5 A1B $T_{min_{AGW}}$) showing a) the mean, b) annual variability and c) mean, annual variability and step changes for a high emissions pathway.	145
Figure 36. Selected local, regional and global climate variables covering air and sea surface temperature (Goddard Institute of Space Studies (GISS) data, Hadley/CRUt3 data, BoM and Jones (2012)), ocean heat content (NOAA NODC) and tide gauge records (PSMSL). Statistically significant step changes to the 1% and 5% level analysed with the bivariate test (left) and STARS test (right) are shown with year and size of change between periods. Method of analysis described in Jones (2012).	150

List of tables

<i>Table 1. Framework, methodologies and methods and tools hierarchies used in this project. ..</i>	<i>13</i>
<i>Table 2. Australian Government funding for disaster prevention and recovery, 2005-06 to 2010-11 (Productivity Commission, 2012)</i>	<i>24</i>
<i>Table 3. Climate variables potentially associated with greenhouse-induced rapid changes with evidence and notes.</i>	<i>29</i>
<i>Table 4. Current adaptation and associated policies and regulation landscape.</i>	<i>49</i>
<i>Table 5. Total number of deaths and valuation by 2020 and 2050 due to heatwaves under baseline and climate change scenarios.</i>	<i>51</i>
<i>Table 6. Total number of deaths and valuation by 2020, 2050 and 2099 due to heatwaves under baseline and climate scenarios representing gradual and variable change.</i>	<i>53</i>
<i>Table 7. Total damage costs to Vic agricultural industry under baseline and climate change scenarios by 2020 and 2050, \$millions \$AUD 2011</i>	<i>55</i>
<i>Table 8. Total bushfire damage costs to Vic timber industry under baseline and climate scenarios by 2020 and 2050, \$millions AUD2011.</i>	<i>55</i>
<i>Table 9. Total losses to agriculture and timber production by 2020, 2050 and 2099 due to changing fire risk under baseline and climate scenarios representing gradual and variable change.....</i>	<i>57</i>
<i>Table 10. Australian sectors showing adaptation situation with main threats and opportunities, couched in general economic terms.</i>	<i>64</i>
<i>Table 11. The predicted total damage cost of bushfires in Southeast Australia to ecosystem services by 2020 and 2050 (\$ millions) (Keating and Handmer, 2013).</i>	<i>71</i>
<i>Table 12. Market-based instruments by type (Whitten et al., 2004)</i>	<i>73</i>
<i>Table 13. Comparison of neoclassical and the extended IAD framework.</i>	<i>75</i>
<i>Table 14. Core needs and attributed value of key risk by scenario.</i>	<i>87</i>
<i>Table 15. Comparison of climate change attributes with widely held preferences for the types of decision-making people prefer (Young, 2012).</i>	<i>102</i>
<i>Table 16. Summary of task-oriented needs for research.....</i>	<i>102</i>
<i>Table 17. Summary of capacities needed to deal with rapid changes in climate extremes.</i>	<i>110</i>
<i>Table 18. Industry sector specific adaptation requirements</i>	<i>111</i>
<i>Table 19. Catchment Management Organisations (CMO) Governance Criteria (Roberts et al., 2011)</i>	<i>114</i>
<i>Table 20. Summary for each of the five adaptation clusters detailing risk, risk propagation and major types of adaptation policy for each (examples need further development).</i>	<i>117</i>
<i>Table 21. Key questions for policymakers</i>	<i>127</i>

ABSTRACT

The methods used to plan adaptation to climate change have been heavily influenced by scientific narratives of gradual change and economic narratives of marginal adjustments to that change. An investigation of the theoretical aspects of how the climate changes suggests that scientific narratives of climate change are socially constructed, biasing scientific narratives to descriptions of gradual as opposed rapid, non-linear change. Evidence of widespread step changes in recent climate records and in model projections of future climate is being overlooked because of this. Step-wise climate change has the potential to produce rapid increases in extreme events that can cross institutional, geographical and sectoral domains.

Likewise, orthodox economics is not well suited to the deep uncertainty faced under climate change, requiring a multi-faceted approach to adaptation. The presence of tangible and intangible values range across five adaptation clusters: goods; services; capital assets and infrastructure; social assets and infrastructure; and natural assets and infrastructure. Standard economic methods have difficulty in giving adequate weight to the different types of values across these clusters. They also do not account well for the inter-connectedness of impacts and subsequent responses between agents in the economy. As a result, many highly-valued aspects of human and environmental capital are being overlooked.

Recent extreme events are already pressuring areas of public policy, and national strategies for emergency response and disaster risk reduction are being developed as a consequence. However, the potential for an escalation of total damage costs due to rapid change requires a coordinated approach at the institutional level, involving all levels of government, the private sector and civil society.

One of the largest risks of maladaptation is the potential for un-owned risks, as risks propagate across domains and responsibility for their management is poorly allocated between public and private interests, and between the roles of the individual and civil society. Economic strategies developed by the disaster community for disaster response and risk reduction provide a base to work from, but many gaps remain.

We have developed a framework for valuing adaptation that has the following aspects: the valuation of impacts thus estimating values at risk, the evaluation of different adaptation options and strategies based on cost, and the valuation of benefits expressed as a combination of the benefits of avoided damages and a range of institutional values such as equity, justice, sustainability and profit.

The choice of economic methods and tools used to assess adaptation depends largely on the ability to constrain uncertainty around problems (predictive uncertainty) and solutions (outcome uncertainty). Orthodox methods can be used where both are constrained, portfolio methodologies where problems are constrained and robust methodologies where solutions are constrained. Where both are unconstrained, process-based methods utilising innovation methods and adaptive management are most suitable. All methods should involve stakeholders where possible.

Innovative processes methods that enable transformation will be required in some circumstances, to allow institutions, sectors and communities to prepare for anticipated major change.

EXECUTIVE SUMMARY

Recent climate extremes experienced in Australia have been more severe and produced more severe impacts than suggested by conventional climate scenarios and impact models. Analysis of recent Australian climate change shows that Australia has warmed in two episodes: 1968–73 and 1994–97 with little change in between. Rainfall decreased rapidly by 85mm or 12% in SW WA in 1968 and increased rapidly by 22% in northern Australia in 1973. All these changes occurred as statistically-significant step changes. Similar rapid climate changes are widespread, occurring in all regions of the world and in a number of climate variables. They also occur in climate model simulations of temperature and rainfall for Australia.

If these changes are so widespread, why have they not been incorporated into the analysis and communication of climate science for impact and adaptation studies?

The climate science literature openly discusses the possibility that climate change is non-linear, but this has not made its way into practice. The answer is in science narratives, which are the main means by which sense is made from scientific findings and communicated between scientists and the community. These narratives influence the framing and development of approaches to adaptation practice and policy.

The strongest narrative currently accompanying adaptation is that of gradualism. Current statistical approaches manage climate uncertainty by smoothing over climate variability, biasing the theoretical understanding of how climate changes. Climate change is overwhelmingly described as a gradual change in variables such as mean temperature and rainfall. If adaptation is thought of as an adjustment to those changes, then the practice of adaptation too, becomes gradual.

This narrative is related to similar narratives of gradual change in classical economics. Existing economic models aim to optimise outcomes by making the world simpler than it is, and by smoothing over variations.

Richer approaches in both climate and in economics are needed to develop adequate valuation methods and adaptation policies to rapid climate change. Disaster economics, which researches the negative aspects of maladaptation and the positive aspects of transformation, is the source of some of these approaches.

Using two case studies of direct climate model output, we show that for heat stress and fire, the results produce rapid changes in impacts during the late 20th and 21st centuries that are much more economically damaging than smoothed data from the same models.

The broad physical and social economy is divided into five adaptation clusters: goods, services, capital assets and infrastructure, social assets and infrastructure and natural assets and infrastructure. The first three are well represented in the monetary economy (as tangible values) and the latter two, not so well (as intangible values). These clusters produce very different patterns of risk under climate change.

“Value is not a logical process because value is not the just about cost, it is also about what we as individuals and communities hold as precious to us.”

The greatest risk with rapid climate change is with changing extreme events such as heat stress, fires, floods and storm events. Rapid climate change can change these extremes rapidly, and has already done so for heat and fire risk in SE Australia.

2 Valuing Adaptation under Rapid Change

Such changes can escalate and combine in a variety of ways, propagating risks across institutional, spatial and sectoral domains. For example, a series of extreme events may propagate economic risks from state to federal level, and from the private to the public sector if properties are under-insured. Production systems may be interrupted and transport disrupted. Social capital, if eroded may transfer from self-reliance to government relief and natural capital may degrade.

Some of these risks may be owned by institutional entities but others may be un-owned where no institutional body will take responsibility for ensuring that value is maintained. Currently, there is no clear understanding as to where institutional thresholds are or what the likely consequences are if these thresholds are crossed. Institutional frameworks and structures are, for the most part, inflexible and siloed. Consideration as to how to undertake transformation of these structures and processes is needed if rapid change if the risks posed by rapid change are to be effectively managed.

The current focus on expenditure on disaster response may actually be counterproductive to reducing risk at both a financial and institutional level. Present disaster response is outweighing investment in resilience programs. Planned adaptation is needed to recover this imbalance.

The project describes an economic framework for assessing values at risk, the cost of adaptation and the social and economic from implementing adaptation. This framework is polycentric, in that it can accommodate a wide range of methods and tools rather than concentrating on cost benefit analysis and its various modifications.

The values and costs associated with the impacts also need to be assessed fully over differing time frames (short, medium, long-term). This will require blending of frameworks and methodologies from areas of economics addressing disasters, and environmental and social values. The current framing of discount rates provides no clear direction as to what rates are appropriate for different circumstances, especially over long time frames.

To meet these challenges we need a new generation of adaptation policies, on a larger scale than currently envisaged and with different intellectual foundations. These policies must address the likelihood of abrupt climate change and pervasive economic and social impacts, even though the nature, timing and location of those impacts remain uncertain. They must be cooperative and polycentric, and involve the various forms of the public and private sectors at both the national, state and local levels. They will require attention to diverse risks and the values they threaten, to the extension of many risks across domains, to the key role of innovation in creating adequate responses and require ongoing adaptive management strategies in cases in which there is deep uncertainty about both the problem and its solution.

Key aspects needed are:

- The guided transformation of current institutional structures and systems. In particular the development of collaborative frameworks that enable decision making within and across a number of institutions and frameworks to assist with decision making under uncertainty.
- The development of fit for task economic frameworks, capable of integrating and assessing a diversity of costs and values across different time scales. In particular 'intangible' costs need to be included more fully in these assessments. The disparity between different discount rates used in different institutional settings needs to be addressed.

- The integration into adaptation practice and policy of frameworks and methods that are iterative and reflexive, such as innovation and assurance processes. These are already in use and have established mechanisms that allow for: decision-making with uncertain outcomes, the introduction of new ideas and technologies, social interactions, knowledge development and collaboration across a broad range of stakeholders.
- Further research to better understand the full ramifications of rapid change and how it will impact current systems and institutions and assess where possible thresholds might be and where they cross institutional domains. In particular the development of models that include different types of extreme events in a number of contexts and sequences.
- Development of capacity through appropriate resourcing, the development of knowledge and communication that is 'fit for purpose' for end users and governance to support this.

1. OBJECTIVES OF THE RESEARCH

The objective of this study is to develop an economic methodology at the institutional scale to support decision-making on adaptation actions and investments ranging from adjustment to transformation, given the likelihood of rapid changes in regional climate leading to rapid changes in extremes and accompanying risk of disaster. The methodology explicitly identifies and responds to the limitations in current approaches extending from climate science through to the implementation of adaptation. It draws widely from different disciplines and accounts for rapidly changing climatic and socio-economic factors.

The original aims of the study (slightly reworded for clarity) were to:

- Understand the appropriate mix between public and private adaptation and risk sharing;
- Understand the impacts of changing climate extremes on the economics of valuing adaptations;
- Identify critical points where the economics of adaptation has not yet integrated recent findings from climate science and offer suggested improvements; and
- Identify valuation tools for end-users that cope with the realities of uncertain damage functions, ambiguous climate futures and the potential for non-marginal change.

While not all of the above aims have been met, substantial progress has been made on all four:

- The concept of risk ownership applied to adaptation to climate change has great potential to delineate responsibility between different institutional players;
- The economic impacts of rapid changes are clear, but valuing adaptation remains highly context specific, although we have identified some high level principles;
- We are recommending significant changes to how climate information is used, with less reliance on predicting mean regional climate change; and
- While some emphasis has been placed on tools, we place a greater emphasis on decision-making processes, particularly at the institutional scale.

These points are elaborated on in the final chapter.

1.1 *Background to the project*

The project focus is on using economic principles to support collective adaptation decisions at the institutional scale, how those decisions can support a range of values, and how they are governed. It concentrates on developing an institutional framework that aims to cover actions and investments ranging from adjustment to transformation. It draws on a wide range of literature including the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation ([IPCC, 2012b](#)).

The framework also accounts for recent scientific evidence that human-induced climate change is not a gradual process independent of natural climate variability. This means that rapid changes in the frequency and magnitude of a range of severe weather events are a normal part of climate change, and should therefore be factored into the adaptation process. The dominant gradualist model of adaptation planning assumes that climate change will proceed incrementally – focusing on the magnitude of climate change occurring within a specific planning horizon and extrapolating smooth changes within that horizon ([Downing et al., 1997](#); [Smithers and Smit, 1997](#); [Dessai and van der](#)

[Sluijs, 2007](#); [Millar et al., 2007](#)). We show that this model is a socially constructed statistical model that does not reflect observational evidence or scientific theory.

Evidence of rapid change is contained within recently observed climate records. For example, south-eastern Australia has experienced almost 1°C of anthropogenic warming, most of which occurred in two episodes: 1968–73 and 1994–97 ([Jones, 2012](#)). Certain extreme events, such as extreme heat and fire danger, have also changed faster than mean temperature changes in some regions. Climate model output, if analysed appropriately, shows similar non-linearity ([Jones, 2012](#)). Extreme events are very difficult to predict with any skill ([IPCC, 2012b](#)), but like earthquakes, can be anticipated in many cases. Therefore, lack of predictability should not preclude planning for rapid climate change if it is being measured in both observations and climate model data.

With a few exceptions ([Adger, 2000](#); [Naess et al., 2005](#)), adaptation at the institutional scale has also been largely overlooked in the literature and is difficult to assess. To date, the economics of adaptation has largely concentrated on the individual adaptation actions needed to manage anticipated climate change ([Gagnon-Lebrun and Agrawala, 2006](#); [Hallegatte et al., 2011](#)). To a lesser extent they have also dealt with increasing adaptive capacity ([Adger et al., 2007](#)). Decision-making on adaptation involves not just decisions on how to adapt, but the broad institutional context within which such decisions are made and how they are implemented and managed over their operational lifespan.

The main focus of this project is on the institutional and governance structures involved in both public and private adaptation in Australia. Institutions here are considered as clusters of rights, rules and decision-making procedures that give rise to social practices ([Young et al., 2008](#)). Governance structures considered here are those rules and practices designed to foster adaptation to climate change, but other governance structures that influence adaptation are also relevant. Some governance structures, such as government policy and legal frameworks are formal while others, such as market behaviour and community-based practices, are both formal and informal.

Iterative risk management is used to address system processes, especially in how risk is propagated across scales and between systems. Here, an identifiable geographic or institutional scale is referred to as a domain, to distinguish interactions within a specific domain from the propagation of risk across domains. A heterodox economic framework¹ is applied, where specific economic methods and tools are matched to their area of strength. This has been identified as a necessary approach to adaptation because of its complexity and context-specific nature ([Keating and Handmer, 2011b](#); [Oberlack and Neumärker, 2011](#)).

Of special interest is where risk propagates from one domain to another – as in so-called cross-cutting effects – warranting a policy response. For example, adaptation at the local scale is largely a microeconomic issue where the bottom-up assessment of impacts aims to identify and select a set of cost-effective actions. However, at the national scale, where repairing the cumulative costs of these actions may require large injections of finance or where large uninsured losses are mounting, adaptation becomes a macroeconomic issue.

How adaptation actions propagate across domains should be of particular interest to policy-makers because policies designed for single domains (e.g., the housing sector

¹ Heterodox economic frameworks use multiple methods for setting values rather than an orthodox framework that uses only single method, such as welfare or utility.

or agriculture), may break down. Two such cases are when private risk accumulating from many individuals needs to be managed as a public risk after a disaster, or when risks shift from one economic sector to another (e.g., from production systems or households to finance). Opportunities for creative policy-making across domains also exist if specific pathways that transfer co-benefits of adaptation actions across those domains can be identified. This topic has not been very well addressed in the adaptation literature.

At the institutional level, individual government bodies (departments, local government), industry sectors, corporations and other organisations may be able to manage adaptation within specific domains but would need increased capacity to do so. If increased adaptive capacity is warranted, cross-institutional support and the requisite governance arrangements to facilitate this may be required. The propagation of risk between domains or the creation of new risks caused by maladaptation or by a set of actions accruing at one scale and transferring to another will also require cross-institutional and governance support.

We have adapted two frameworks for this project. The first is a generic problem-solution framework for implementing adaptation (Young, 2012) that separates the problem phase from the solution phase of the adaptation process. It provides two primary framings for this: risk and innovation, and three key tasks: problem identification, assessment and implementation of actions. This was developed to assist practitioners identify where they were in the adaptation process and the different options available in relation to framing, tools and processes as well as appropriate modes of communication that related to specific tasks.

The context for identifying problems sits squarely within the analytic phase of risk, whereas the context for implementing solutions is associated with innovation models and processes. Economics in assessing values at risk and the cost of different strategies bridges the two phases.

The second framework assesses adaptation at the institutional scale. For this task, we have adapted the institutional analysis and development (IAD) framework of [Ostrom \(2005, 2011\)](#), institutional and governance analysis ([Young et al., 2008](#)), economic frameworks summarised by [Hallegatte et al. \(2011\)](#) and climate risk approaches ([Jones, 2001](#); [Jones, 2004a](#); [Jones et al., 2007](#); [Jones and Preston, 2011](#)).

The IAD framework has been applied as an organising methodology in two settings:

1. to understand the current state of play; and
1. to explore potential future strategies that range from transition to transformation.

2. RESEARCH ACTIVITIES AND METHODS

2.1 *Project design and methods*

The project combines new evidence of rapid change in climate, especially climate extremes, with economics from the disasters assessment field. These rapid changes have the potential to result in impacts that cross geographical, political, social and economic domains, causing significant harm if left unmanaged. New economic approaches to valuing adaptation to rapid change are developed from disaster economic and economic approaches for adaptation that have been developed for decision-making under deep uncertainty.

Rapid climate changes have been assessed using statistical tools used to diagnose the likelihood of step-like changes in noisy time series. These have been modified to ensure that they are not producing false positives from time series of observed and modelled climate. Many different time series from observed climate data from around the world and simulated future temperature and rainfall data from Australia show that step changes are common in historical records and climate model data. Why have such changes been overlooked in scientific analysis of climate change and the resulting assessments of climate impacts?

To answer this, the current statistical approaches to measuring climate change were assessed for their historical and social legacies. While very useful, the almost total reliance on such tools to analyse and communicate climate change in order to manage the resulting uncertainty have obscured the theoretical understanding of how the climate changes. This understanding is split between climate change being smooth and independent of climate variability, and climate change being non-linear and interacting with climate variability. The project results show that the latter is the most plausible explanation, given the widespread evidence of step-like changes in climate data.

The strong legacy of these changes is traced through narrative assessment. Narratives are the main means by which sense is made from scientific findings and communicated between scientists and the community. These narratives influence the framing and development of approaches to adaptation. The methods and values informing these narratives have their origin in the scientific enlightenment. They have resulted in a narrative of gradual change, which informs how the climate changes. Applied to adaptation they form a narrative of gradual change that we have called the gradualist narrative. Ironically, the origins of these narratives in the enlightenment also underpin similar narratives of gradual change in classical economics.

The likelihood of rapid changes in climate – and particularly in climate extremes – required that the economics of adaptation be re-assessed. In addition to investigating how disaster economics views aspects such as maladaptation and transformation, we looked at orthodox approaches to valuing adaptation and how they need to be modified. The limitations of current approaches to economic assessment of adaptation, valuing intangibles, assessing the risk of maladaptation, and the costs and benefits of transformative adaptation are described and addressed.

The possibility of risks crossing domains at an increasing rate was investigated by looking at how recent climate events precipitated responses from areas of government not normally involved in emergency management. We adopted an approach that looked at these risks on the institutional scale, adapting Ostrom's IAD framework [Ostrom \(2005, 2007a, 2011\)](#) to look at collective decisions on adaptation. Four key elements from [Hallegatte \(2011\)](#) – information, regulation and standards, institutions

and public investment – have been integrated into this framework. Institutions provide governance for knowledge, regulation and standards, and public/private investment.

Finally, one of the main ways to overcome the barrier of predictive uncertainty, particularly in complex social-ecological systems, is to adopt innovation processes for decision-making. These help manage the knowledge and communication aspects of adaptation and but also assist in the implementation of adaptation –one of the missing links in current methods. Innovation methods inform two of the processes commonly used to manage climate-related uncertainty: iterative risk management and adaptive management.

A workshop (originally planned for March 2012) that aimed to develop the main concepts was replaced by a workshop held in November 2012 that applied the proposed institutional framework developed by the project team.

A decision-making framework has, for application of economic methods, been developed that separates the decision-making process into a problem-solution construct. Economic methods move from valuing the problem to costing alternative solutions and assessing their benefits. The IAD framework is used as an organising framework and the problem-solution economic framework as a decision-making framework.

The approach used by the project is, in many ways, complementary to existing approaches, but contains some significant differences:

- the incorporation of rapid climate change and its impacts on economic assessments;
- applying salient climate information to decision-making by asking whether it poses a credible risk that needs to be managed, rather than filtering such information according to whether it is 'predictable';
- specifically addressing rapid changes in climate extremes and their economic impacts instead of assuming gradual change in both the mean and extremes;
- addressing the collective needs of adaptation across institutions at the regional to national scale rather than focusing on a specific event type, sector or region; and
- concentrating on the adaptation deficit of both present and future climate without trying to separate climate into components of change and variability.

2.2 Report structure

This section deals with project design and methods, presenting two frameworks: a problem-solution-implementation framework that combines risk and innovation in Section 2.3, and the IAD framework in Section 2.4. Methods of climate change analysis – describing methods for analysing gradual and rapid change – are described in Section 2.5.

Section 3 then describes the results of the study laid out according to a problem-solution-implementation approach. Section 3.1 is about understanding the rapid climate change. Recent events caused by climate extremes and the resulting impacts are shown (Section 3.1.1), along with recent rapid climate change in Australia. The anatomy of rapid change, along with descriptions of coping ability and thresholds is described in Section 3.1.3.

Section 3.2 covers the current gradualist approaches to assessing climate change, impacts and adaptation. Scientific and adaptation narratives are introduced and

described, followed by impact and adaptation assessment, orthodox economic approaches and current adaptation policy.

Section 3.3 covers the understanding of the economic response to rapid change. Two case studies on heat extremes and fire show how rapid changes can drive up the costs of impacts (Sections 3.3.1 and 3.3.2). These case studies contrast the costs modelled under gradual change and then use climate model data containing rapid changes to show how significant economic shocks can occur as part of ordinary climate change. How these risks cross domains in the way that disasters affect us now is described in Section 3.3.3. Different values associated with impacts are described in five adaptation clusters: goods; services; capital assets and infrastructure; social assets and infrastructure; and natural assets and infrastructure. Each cluster covers one or more sectors of the economy (Section 3.3.4), and also contains values not measured as part of the conventional economy. Clusters were chosen by how the economic costs of impacts and adaptation are represented, how the monetary and non-monetary aspects of value are viewed, and their institutional setting. These clusters are supported by adaptive capacity that has both public and private components.

A national synthesis describes how these risks may manifest at the national scale and details current research needs prompted by question raised during the project (Section 3.3.5). Finally, in this section, we describe a range of economic methods and tools that are used for valuing adaptation (Section 3.3.6). The major filters for managing risks through adaptation at the institutional level are: who values the risk and who owns the risk (the latter can be separated into who is responsible for the risk); who pays for the risk if it occurs; and who pays for managing the risk. Ownership may be invested in a single entity but often extends across institutions and domains. Valuation methods need to be appropriate within specific institutional contexts.

Section 3.4 describes the evaluation of solutions. Section 3.4.1 outlines the framework for economic approaches to the valuation of risks associated with changing impacts, the costing of adaptation options and valuing the benefits those options provide. The workshop results where the problem-solution framework was applied to scenarios of rapid change and assessed for how the resulting risks crossed domains, surveyed the values at risk and proposed a number of solutions for selected problems, are reported on (Section 3.4.2). The tools and methods used in the evaluation process are briefly described with their strengths and weaknesses in Section 3.4.3.

A key part of adaptive capacity is understanding and managing the process of knowledge development and communication. The construction of formal and informal narratives is an important aspect of communication. The role of innovation in implementing planned adaptation – where solutions are part of common practice – is crucial (Section 3.4.4). Transformation is a special case, requiring significant resources and the use of innovation processes (Section 3.4.5). Maladaptation can occur if inappropriate assumptions are applied, or if adaptations are considered at one scale but manifest negatively at another scale. Institutional-scale assessment is important to void such outcomes (Section 3.4.6).

Capacity and governance are closely linked and are both important elements of institutions. Rapid climate change requires significant additional capacity over and above that being assumed to adapt to gradual climate change (Section 3.4.7). To develop these capacities, existing policies will require revisiting and new policy initiatives may need to be considered (Section 3.4.8).

Implementation covering policy assessment, scenarios and application of economic tools is covered in Section 3.5. Gaps and future research options are briefly outlined in Section 5.

2.3 Economic framework for adaptation

The economic framework for valuing adaptation is a generic problem-solution framework for implementing adaptation using risk and innovation framing (see Appendix B) that separates the problem phase of climate change and its impacts from the solution phase of the adaptation process. This framework is also cognitive and resonates strongly with the decision-making and risk literature. Behavioural economics shows that people frame problems and solutions in very different ways (([Kahneman and Tversky, 1979](#); [Tversky and Kahneman, 1992](#); [Tversky and Kahneman, 2000](#); [Kahneman, 2003, 2011](#)), so that problem thinking is very different to solution thinking. Not managing the transition between the two sufficiently leads to risk amplification ([Kasperson, 1992](#); [Burns et al., 1993](#); [Pidgeon et al., 2003](#); [Rosa, 2003](#); [Renn, 2011](#)), or the risk trap ([Beck, 2000](#)) – where the risk of uncertain solutions competes with the risks of uncertain problems, often leading to decision paralysis ([Jones, 2011](#)).

The transition between problem and solution is managed using economics. Risks are valued at the problem stage, different options are then proposed and costed, and the benefits of implementation valued. This part of the risk process, often referred to as the risk management component, is given over to innovation models and processes. Innovation is the key tool for decision-making under ‘deep uncertainty’ – where both problems and solutions cannot be predicted with any great confidence, and ongoing learning and knowledge development are part of implementation. In this context, it is largely synonymous with iterative risk management or adaptive management.

Figure 1 shows that both the problem and potential solution inform the economic analysis, where understanding how adaptation will be applied becomes just as important as understanding the climate risks that necessitate that adaptation.

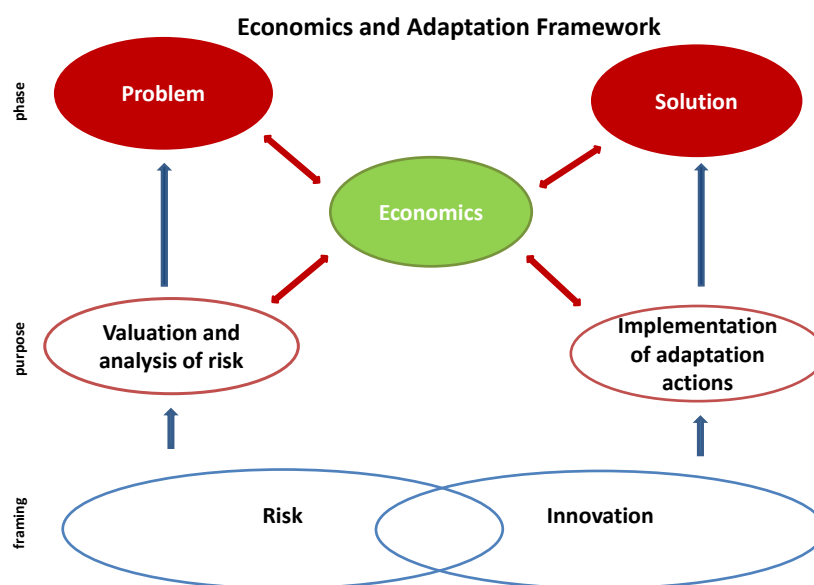


Figure 1. Economics and adaptation decision-making framework with a problem-solution focus (Adapted from Young, 2012, Appendix B).

2.4 Institutional Analysis and Development framework

Ostrom's (2005, 2011) IAD framework is described in Figure 2. It has external influences that influence the problem or situation and internally has interactions and outcomes that are affected by evaluation criteria. The model is economic and can accommodate different economic theories as needed. The external influences are climate change. The action situation and interactions describe the valuation of adaptation to rapid change.

[Ostrom \(2011\)](#) uses framework, theory and models as a hierarchical foundation for institutional analysis. The framework and theory are used to construct the IAD process and the models are used to assess the interactions and outcomes within the framework. Her use of the framework-theory hierarchy is to describe the application of economic theory to an institutional framework.

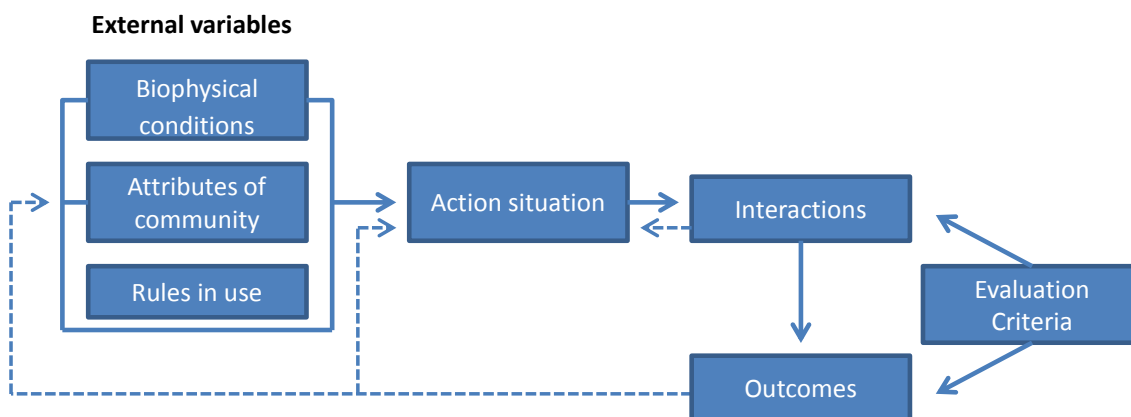


Figure 2. A framework for institutional analysis ([Ostrom, 2005, 2011](#)).

Here, we apply a hierarchical foundation of framework, methodology and methods and tools. The framework level applies paradigms that include theory, methods and values. This, more or less, expresses the platform from which one views the world ([e.g., Hacking, 1993](#)) and everything that follows from this – methodologies, methods and tools – depend on this platform.

The framework organises the elements and general relationships for institutional analysis that can then be pursued with diagnostic and prescriptive enquiry. For this project, the overall framework concerns adaptation to climate change –adaptation to rapid changes in climate extremes in particular. The framework needs to encompass all the information available to actors, the flow of activities and who receives what costs and who pays. In Table 1, the framework, methodologies and methods and tools hierarchies covering the IAD, science, economics and institutions are outlined.

Questions that need to be addressed are:

- How are specific impacts valued and by whom?
- How can we cost them in order to fully assess the value of adaptation to rapid climate change?
- How can different methods of valuation support decision-making and future investments for adaptation?

The framework is strongly influenced by the external variables listed in Figure 2; the biophysical system, community attributes and rules in use. These external variables are surveyed to determine the scope of what the framework needs to contain. The biophysical conditions describe the state of the climate and rate of climate change that

result in rapidly changing impacts and risks. The attributes of the community include the actors involved and their institutional context. The rules in use are shared understandings amongst the actors that refer to what actions or states are permitted, required or prohibited, and these may be explicit or implicit ([Ostrom, 2011](#)).

The IAD framework is used to organise our understanding of the risks of rapid change at the institutional level and the problem-solution framework is used as a decision-making framework. The next level down is theory, addressed by selecting the most appropriate parts of the framework needed to understand and explain process, and to predict potential outcomes.

Table 1. Framework, methodologies and methods and tools hierarchies used in this project.

	General	IAD	Science	Economics	Institution
Framework	The platform of understanding surrounding the generation and use of knowledge and application of values	The general approach taking in the external inputs, nature of the problem, action situation and outcomes	Paradigm: a collection of theory, methods and values used to describe a disciplinary approach	The philosophical underpinnings of ways to assess values and allocate resources in the future	The ‘mission statement’ and major aspirations of an institution
Methodologies	The ways in which that knowledge is used to exercise those values	The ways in which problems are described and solutions found to evaluate different courses of action	The ways in which those approaches are applied to understand phenomena, problems and solutions	The ways in which the benefits of a given course of action is valued	The narratives and rules by which an institution carries out its mission
Methods and Tools	The means by which that knowledge applied	The individual tools used to apply those methodologies	The individual tools used to analyse and apply those approaches	The individual tools used to apply those actions	The tools used by that institution as writ into practice

Two important areas of theory are:

1. the science of climate change and how it contributes to the understanding of impacts and adaptation under rapid change; and
2. The economics of impacts and adaptation.

Models are used to apply theory but contain assumptions about how a specific theory should be represented. For climate science, the dominant model is the signal-to-noise model (STNM) that measures and communicates climate change within a forecasting paradigm. Scenario-led approaches are also very important and convey plausibility but not probability.

For economics, existing models are dominated by cost-benefit analysis (CBA) but here we survey a wide range of approaches to manage the wide range of decision-making contexts. Other important theoretical considerations include theories associated with risk management, psychology, behavioural economics and communication.

The framework is shown in more detail in Figure 3. Action situations involve actors, domains and decision-types working according to a set of interactions and outcomes against which costs and benefits (very broadly defined) can be attached. Here, the interactions focus on climate impacts, risks and adaptation decision-making. Outcomes

are assessed according to a set of evaluation criteria that cover aspects of value, institutional performance and specific policy outcomes. These topics are summarised in the following sections, with action situations dealt with first because of their central nature to the framework.

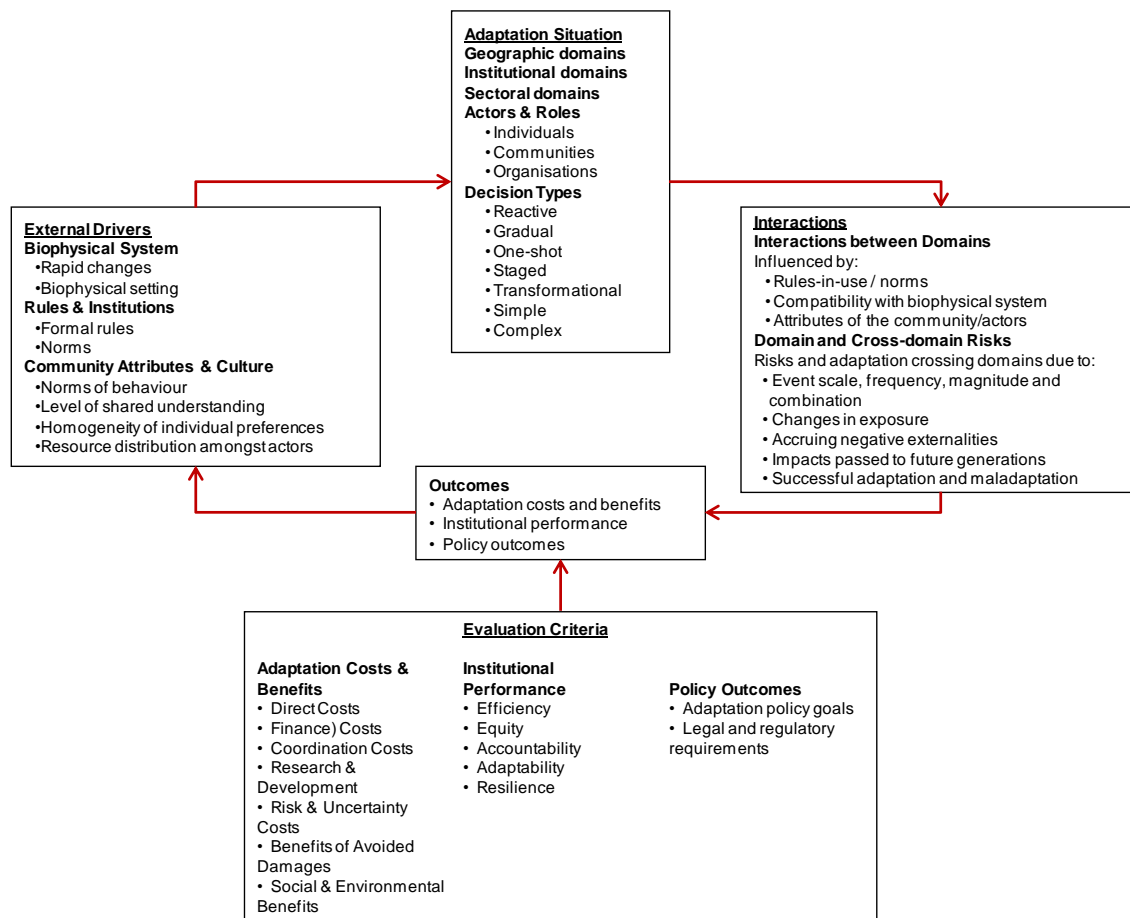


Figure 3. Institutional framework for assessing the economics of adaptation (Based on Ostrom, 2011 and others).

2.4.1 Action/adaptation situations

Problems or situations are identified through a conceptual unit – called an action situation – that can be utilised to describe, analyse, predict, and explain behaviour within institutional arrangements (Ostrom, 2005). The action situations in this project cover rapid climate change and how the resulting risks cross-institutional domains. An action situation involves a set of actors, their institutional positions and an allowable set of actions they are able to undertake. Interactions and outcomes are linked through a set of evaluative criteria.

A specific actor in a situation includes assumptions about four types of variable (Ostrom, 2011):

1. the resources that an actor brings to a situation;
2. the valuation actors assign to states of the world and to actions;
3. the way actors acquire, process, retain, and use knowledge and information; and
4. the processes actors use for selection of particular courses of action.

Most analyses stop at the surface levels of this framework, but further depth can be gained by addressing the factors that have influenced the structure of the current

situation ([Kiser and Ostrom, 1982](#)) and by investigating how an action situation changes over time due to altered perceptions and new information and strategies ([Ostrom, 2007b](#); [Ostrom et al., 2007](#)).

In this project we have found the way actors acquire, process, retain, and use knowledge and information particularly important. The generation and transfer of knowledge and information between research, technology, technology transfer and practice is the glue that holds the framework together. The means by which this is done – through rules and regulations, narratives, reports, interpersonal and inter-group discourse – are many and diverse, but narratives, formal and informal, are central.

We focus on how knowledge is generated at three stages:

1. **Research** – research into, and communication of, scientific knowledge to understand problems;
2. **Technology** – the development of adaptation as a social technology to develop solutions; and
3. **Implementation** – the application of adaptation actions, followed by monitoring and review.

Narratives dominate the communication between these stages. Formal and informal knowledge are both important, because adaptation requires the blending of different types of knowledge. Various forms of knowledge interact through a network of formal statements, findings, rules, recommendations and narratives. The three most important epistemological groupings investigated in this framework are science, risk and adaptation. Here, adaptation is also considered as a social technology.

More recent work by Ostrom and colleagues has expanded the reach of the IAD framework towards social-ecological systems ([Ostrom, 2007b](#); [Ostrom et al., 2007](#)). This expands the system from having a limited set of external variables grouped under the biophysical system, community attributes and rules in use, to one that affects and is affected by social, economic and political settings, and related ecosystems. The actors interacting in action situations generate interactions and outcomes that are affected by and affect a resource system, resource units and governance systems ([Ostrom, 2011](#)).

This is certainly the case for adaptation to climate change where risks are being propagated across geographic, sectoral and institutional domains. Likewise, the social, economic and political settings that adaptation takes place in at the institutional level cannot be separated from adaptation actions themselves. For example, adaptation in the area of water supply and demand has to take place within a broader framework of water policy, social and cultural attitudes to water and water politics. In this project, we have endeavoured to undertake our analysis at the scale that requires the role of adaptation within the broader social-ecological system to be addressed.

Two critical aspects of the overall social-ecological system affected by climate change are uncertainty and complexity. These aspects mean that solutions are found, not by making and responding to forecasts, but by exploring sets of options within an institutional setting and acting according to a particular set of criteria designed to achieve institutional goals.

Solutions, therefore, are not fixed, but can change according to new information or when the system itself changes sufficiently to warrant a change of strategy. The project framework is a way of managing values within a complex system on an ongoing basis, rather than a single assessment designed to produce a fixed set of outcomes.

2.4.2 External variables

External variables to an action situation include the:

- biophysical system;
- rules and institutions; and
- Community attributes and culture.

The biophysical system describes climate change and its impacts. Instead of taking the conventional route of emphasising adaptation to the most reliable predictions we ask:

- “What climate risks most need to be managed at the institutional scale?”; and
- “What do we know about them?”

To answer these questions adequately, we need to know the values at stake if we failed to adapt to a range of plausible climate risks – characterised as rapid changes in extreme events – and prioritise them on that basis.

The main scientific aim moves away from the current emphasis on predictability (although that remains an important aim of scientific and economic endeavours), towards salience and relevance. Adaptation needs are prioritised by assessing which values are most under threat from rapid changes of uncertain magnitude and frequency, and assessing the contributing factors to their vulnerability. Other endeavours where this type of approach is taken is with security issues, such as serious crime, biosecurity and terrorism, and with disasters such earthquakes and tsunamis that are difficult to forecast.

The above questions require some prior knowledge of how the climate may change over a region and what impacts are likely to ensue. A key finding of this project is that rapid changes in climate risks are currently unpredictable but are far more likely to occur than has been estimated using the conventional methods of climate change analysis (see Section 3.2.2).

Rules in use can be considered as external to an action situation. In this instance, we can recognise two sets of rules that influence adaptation at the institutional scale. The first set deals with methodologies, methods and toolkits that provide guidance on how to conduct adaptation assessments. The second set comprises the formal and informal rules used by actors and institutions that will influence how they adapt. Initially, the first set was constructed quite separately from the second, but more recent assessments are integrating methods and tools with institutional and actor-based rules to produce adaptation assessments that are more context-relevant.

The analysis of institutional rules can be carried out at two levels. Rules can be interpreted at face value or at deeper levels where factors such as community attributes and culture influence how such rules are generated and/or interpreted. Communities of practice will have rules as to how knowledge is generated, communicated and applied. Some of these will have a sound epistemic basis because they have been rigorously tested, but others may be rules of thumb or be taken from a ‘like’ process and adapted to suit the task at hand.

Rules also influence how knowledge is applied. Revisiting the hierarchy of framework, theory and practice, the deepest rules are at the philosophical level where assumptions and values are used to determine how rules frame an action situation. For both climate science and economics, this was carried out by investigating the underlying paradigms influencing theory and methods before identifying how those paradigms inform adaptation narratives.

Scientific narratives are translated into risks where they inform both calculated and perceived risks. Various institutions have different ways in which they calculate and understand risk, and one of the roles in developing the IAD framework in this project is to value risks and risk management within those institutional contexts.

2.4.3 Interactions

The interactions we are most interested in are climate impacts resulting from rapid change that cross geographical domains, or that occur in one location and their effects propagate across institutional domains.

The associated risks represent the valued aspect of those impacts. These may be absorbed by existing capacity within institutions or, if large enough, may propagate to other domains requiring a greater response. An example is where a series of large floods may overwhelm local capacity and livelihoods, requiring intervention in the form of flood relief and perhaps subsequent rezoning and regional redevelopment.

A risk can propagate across geographic scales (e.g., many local risks combining to affect a region or state), across sectors (e.g., from production to finance) and across institutions (e.g., from local government to state and federal governments), or between these types of domain. The crossing of a domain is almost invariably associated with the propagation of that risk across institutions, and with it, some responsibility for management.

Domains include levels of government, public–private domains, regions and sectors. Adaptation decisions can manage risk within a particular location and institutional setting (domain) and across scales (cross-domain). We propose that existing and future risks that propagate across scales are less understood than those that occur at particular locations – therefore they are not ‘visible’ and will be less well-managed.

This lack of visibility is due to several reasons:

- Unclear, partial or disputed ownership of risks as they cross domains;
- Unclear and partial costs associated with the current risks;
- The narrative of gradualism suggests that risks will accumulate slowly, significant events are therefore remote in time, so can be managed at leisure;
- Un-owned risks are undervalued, therefore are considered psychologically remote. If they are valued, then someone else will surely take responsibility for them;
- Significant risks tend to be discounted by individuals; and
- A lack of clarity as to the values at stake, who they affect, and what the potential costs associated will be if they are left unmanaged has not been made clear.

Silo-based policy and planning will also tend to overlook the transmission of risks across scales. More efficient markets by themselves are not sufficient to manage such risks. Adaptation actions may also propagate risks across domains, and when those risks outweigh the net benefits they can be considered as maladaptation. Risk amplification is of particular interest for policy-making because such risks can potentially be large and costly. Here, we treat adaptation as a social technology applied within an innovation framework.

2.4.4 Outcomes

Outcomes vary between those that are predicted by various models, are mandated or aspirational (e.g., achieving a particular state of sustainability). The testing of outcomes is conditional on both the underlying frameworks and on the models and assumptions used. For example, methods such as CBA are not suited to assessing transformative change because they can only assess marginal change in the economy.

Outcomes are measured according to evaluative criteria, institutional performance and policy outcomes. These are not single adaptation decisions, but rather the collective decisions made by various actors within a given action situation.

Evaluation criteria test the broad costs and benefits within a given situation. Some of the methods that can be used include: economic efficiency; equity through fiscal equivalence; redistributive equity; accountability; conformance to values of local actors; and sustainability ([Ostrom, 2011](#)).

Institutional performance ensures that adaptation decisions are consistent with stated institutional aims, and can be implemented as intended and adjusted if new information becomes available.

Policy outcomes test whether a given set of adaptation decisions is better than existing decisions (within the bounds of a specific policy), or manage risks that threaten policy outcomes. Success criteria for such tests are normative and are defined by the policy process.

2.5 Statistical analysis of climate change

The standard view of how the climate changes has been developed through the signal-to-noise model (STNM) (STNM, [Hasselmann, 1979](#); [Santer et al., 1990](#); [Wigley et al., 1999](#); [Hasselmann, 2002](#)). [Santer et al. \(2011\)](#) describe it as: *the warming signal arising from slow, human caused changes in atmospheric concentrations of greenhouse gases is embedded in the background 'noise' of natural climate variability*. Statistical methods are used to extract a climate signal from the noise of random variability. Within the climate system, climate variability is considered to be largely random ([Rodionov, 2006](#); [Roe, 2009](#)), occurring on annual to millennial time scales. Daily to decadal time scales are of most importance for adaptation.

The anthropogenic warming signal is assumed by many to change smoothly (as in Figure 4), with natural variability expressed as noise around that signal ([e.g., Swanson et al., 2009](#)). Figure 4a and b both represent information about temperature change from a single climate simulation, Figure 4a shows the raw annual data from that simulation, and Figure 4b shows the signal interpreted according to a line of non-linear best fit. Most climate change information is processed in this manner and used in a number of ways. The STNM is the mainstay of scenario construction, impact assessment, communication of climate uncertainty and forecasting techniques used to assess likelihoods on a range of scales.

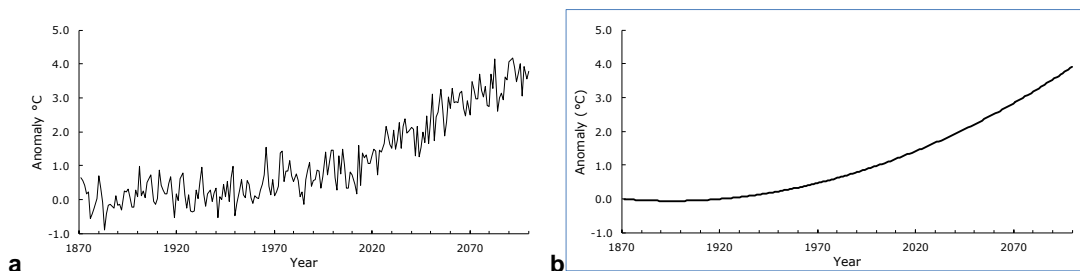


Figure 4. Single climate model simulation for south-east Australian minimum temperature (CSIRO Mk3.5 A1B $T_{min_{AGW}}$) showing a) annual variability, and b) mean change for a high emissions pathway.

An important finding has been that regional mean climate such as rainfall and temperature changes proportionally with global mean temperature ([Santer et al., 1990](#); [Wigley et al., 1999](#)). This allows a technique called pattern scaling, which is the mainstay of regional climate change projections ([Carter et al., 1994](#); [IPCC-TGICA, 1999, 2007](#)). Changes in extremes are often scaled in the same way. Mean changes extracted using the STNM are often used to scale observed climate records to create long time series of variability for a given date in the future. The results of mean change from different models can be combined to provide probabilistic estimates of change. Such results can also be used to communicate uncertainty, as ranges of change and some of the IPCC's most notable diagrams have been constructed this way.

The STNM also enables uncertainty across different models to be combined, allowing the construction of probabilistic projections. Projections with attached likelihood of exceedance (10%, 50%, 90%) were a major feature in the [CSIRO and BoM \(2007\)](#) projections of climate change for Australia.

Although the modern application of this statistical model has become very sophisticated, its origins lie within the scientific enlightenment of the 17th and 18th centuries. The STNM has also proven very useful for a whole range of applications, such as forecasting and scenario construction, so its bona fides amongst the climatological community are very strong.

Methods to assess non-linearity are less well-developed, so have a much lower acceptance amongst the scientific community. Two tools that have been widely used for climatological time series are the bivariate test ([Maronna and Yohai, 1978](#)) and the STARS test ([Rodionov, 2005](#); [Rodionov, 2006](#)). The bivariate test compares two serially independent time series to detect inhomogeneities. It has been used widely for locating artificial step changes due to changes in observing instruments, location or site condition ([Potter, 1981](#); [Bücher and Dessens, 1991](#); [Jones et al., 2001](#); [Kirono and Jones, 2007](#)). It has increasingly been used to assess regime changes in observations ([Lettenmaier et al., 1994](#); [Gan, 1995](#); [Jones, 2010b](#)), and has been adapted to measure step change in single time series by sampling random number series multiple times to reduce statistical uncertainty ([Vivès and Jones, 2005](#)). [Jones \(2012\)](#) adapted it further to sample multiple step change in a time series, combining that with the STNM to assess step and trend behaviour in climate time series.

The sequential t-test analysis of regime shifts (STARS) model has been used widely to assess regime shifts in systems influenced by decadal climate variability ([Rodionov, 2005](#); [Overland et al., 2008](#)). It was tuned to analyse shifts in climate data by using artificial data ([Jones, 2012](#)) and has the advantage of being able to remove autocorrelations (where the current value is influenced by previous values), thus reducing the likelihood of attributing a regime shift to a random event ([Rodionov, 2006](#)).

The bivariate test has also been tested for its robustness by randomising time series before and after a shift to determine whether the shift is truly a step change.

Charting software was adapted to analyse and portray time series to show step and trend behaviour in climate time series and illustrate how climate may change. Most of the time series analysed this way are annual time series of rainfall and maximum and minimum temperature, but other time series include tide gauge sea level records, sea surface temperature, ocean heat content and streamflow.

3. RESULTS AND OUTPUTS

Section 3.1 describes the recent history of rapid climate change in Australia, its scientific background and how it manifests as a series of risks. Section 3.2 describes the current state of play built on narratives of gradual change, covering narratives, current scientific assessment methods, current economic methods and adaptation policy. Section 3.3 addresses the issue of rapid economic change with case studies on heat stress and fire risk. The valuation of adaptation begins with a description of adaptation clusters as an organising structure, a summary of our current understanding at the national scale and a description of the key economic factors for assessing rapid change.

3.1 *Understanding rapid climate change*

3.1.1 *Recent events and climate risks*

The 2009 heatwave in southern Australia

After 13 years of drought and higher than usual temperatures, Melbourne experienced record temperatures in late January–early February 2009. In late January, three days above 40°C (Figure 5) led to power brownouts, public transport network failure, crop and animal losses and widespread heat stress in people ([Queensland University of Technology, 2010](#)).

On Black Saturday (February 7, 2009), temperatures rose to record levels, the system failures experienced in ten days earlier returned and catastrophic fires caused unprecedented amounts of damage. Three hundred and seventy-four people are estimated to have died of heat stress, 173 people died in the fires, over 400 were injured and over 2,000 buildings were lost. The fires were estimated to have cost over \$4 billion of which \$1.3 billion was covered in insurance payouts.

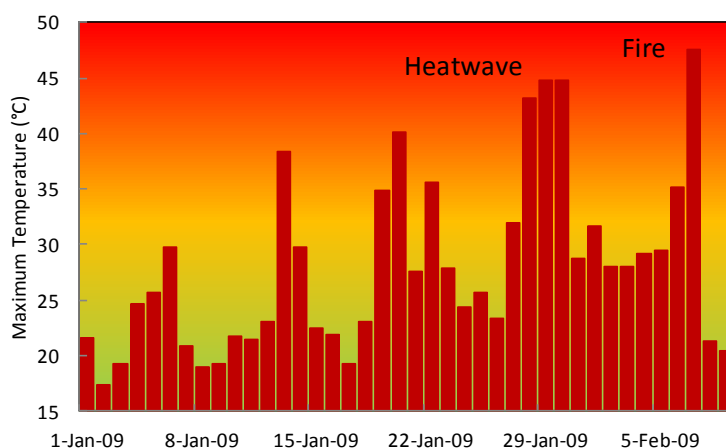


Figure 5. Maximum temperatures measured at Laverton Jan–Feb 2009 showing the heatwave (43.2°C, 44.8°C, and 44.8°C) and fire (Black Saturday; 47.5°C) peaks.

In Melbourne, the Southern Star observation wheel, open only for a month, developed cracks during the heat and remains idle over three years later at a direct cost of over \$100 million with associated losses to businesses in the Docklands area caused by the wheel's closure. Step changes in the frequency of temperatures >35°C Figure 11c and in Forest Fire Danger Index in the region are statistically significant.

These changes have resulted in significant responses that can be considered as adaptation responses, because they changed the way heightened climate risks are managed. For example, Adelaide between Jan 27–Feb 8 2007 experienced 13 days over 33°C, six over 40°C and four over 43°C. One minimum temperature was 33.9°C. Hospital admissions increase 14-fold, ambulance callouts 16-fold and more than 30 people died. Mentally-ill people were identified as vulnerable so the Department of Health revisited their protocols for their 800 clients. Their new benchmark for action is three days above 35°C ([Washington, 2013](#)).

“Above a threshold of 26.7C, we observed a positive association between ambient temperature and hospital admissions for mental and behavioural disorders,” the paper says. “Compared with non-heatwave periods, hospital admissions increased by 7.3 per cent during heat waves ...

“Mortalities attributed to mental and behavioural disorders increased during heat waves in the 65 to 74-year age group and in persons with schizophrenia, schizotypal and delusional disorders. Dementia deaths increased in those up to 65 years of age.” (South Australia’s chief psychiatrist, Dr Peter Tyllis quoted in [Washington \(2013\)](#))

SA Health have not lost one of their clients to heat stress since the summer of 2009/10.

[Keating and Handmer \(2011a\)](#) estimate the current cost of heatwave mortality in Melbourne, using statistical value of life estimates, to be approximately \$1 billion per annum, derived from approximately 300 heatwave deaths. Recent events have also called into question the use of only maximum temperatures to measure heat stress risk – minimum temperatures are critical to building a realistic hazards relationship ([Nairn et al., 2009](#)).

Rapid climate change in Australia

Australia has recently experienced two main periods of rapid change in climate; one in 1968–1973 and the other in 1994–97. To 1967, temperature and rainfall relationships indicate a statistically stationary climate ([Jones, 2012](#)).

Figure 6 shows selected regional records that have undergone statistically significant step changes. Figure 6a shows the only region of Australia, SW Western Australia, that has unequivocally experienced a downward step change in rainfall in 1968. Figure 6b shows average sea surface temperature for Australia, and Figure 6c and d are for maximum and minimum temperature for SE Australia. All records are also shown with a linear trend and 11-year running mean.

All regions of Australia experienced step changes in climate during the period 1968–72. The results for SE Australia are described in [Jones \(2012\)](#), but the results for other regions are presented here for the first time. SW WA experienced a decrease in rainfall of 85 mm, or 12% of the pre-shift period. Minimum temperature increased by 0.6°C but the underlying anthropogenic warming component is estimated to be 0.8°C. Maximum temperature did not increase in the region until 1994 by 0.8°C with an underlying anthropogenic component of 0.6°C. The reasons for the discrepancies for both maximum and minimum temperatures are contained in rainfall-temperature responses. The downward step change of rainfall in SW WA is thought to be at least partially anthropogenic in origin ([IOCI \(Indian Ocean Climate Initiative\), 2002](#); [Power et al., 2005](#); [Fredriksen et al., 2010](#)).

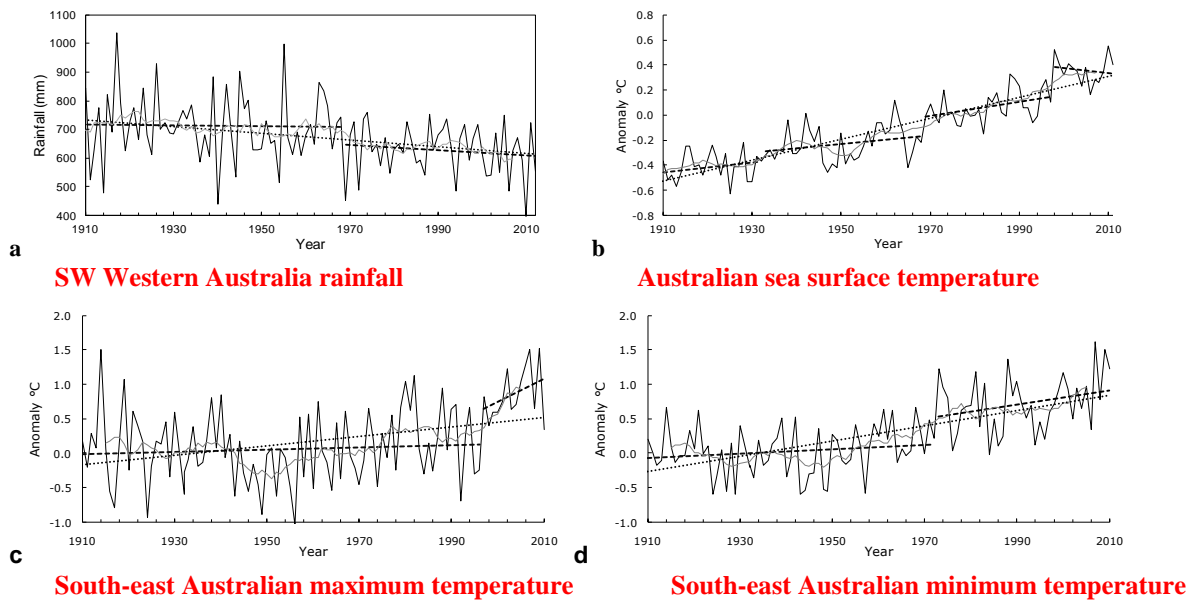


Figure 6. a) South-west WA rainfall 1900–2012, showing statistically significant step and trend profile (long dashes), 11-year running average (light grey) and linear trend (dotted); b) sea surface temperatures for Australia 1910–2011; c) maximum temperature for south-east Australia 1910–2011; and d) minimum temperature for south-east Australia 1910–2011.

In northern Australia, rainfall increased by 22% in 1973. Maximum temperature shows an increase of 0.6°C in 1979, but with the effect of rainfall removed, shows an increase of 0.6 °C in 1969 and a further 0.5°C in 1996. Minimum temperature increased by 0.7°C in 1979, with the anthropogenic component increasing by 0.6°C at the same time.

Natural regime changes have occurred in Australian climate in the past, and appear to be a long-standing feature ([Power et al., 1999](#); [Verdon et al., 2004](#); [Vivès and Jones, 2005](#); [Power et al., 2006](#); [Verdon and Franks, 2006](#); [Lough, 2007](#); [Mills et al., In revision-a](#); [Mills et al., In revision-b](#)). The most recent documented regime change due to natural variability affected eastern Australia in 1946–48 and involved a change from drought-dominated to a flood-dominated rainfall regime.

Economic impacts of recent extremes

This emerging narrative of rapid climate change raises key question for policy-makers and practitioners as to what effects rapid changes in extremes will have on *critical thresholds*.

Data is not routinely collected on the full economic impact of disasters in Australia, but the Insurance Council of Australia makes information available on insurance claims. Between 2000 and 2011, insurance claims for natural disasters in Australia totalled approximately \$16 billion, or an annual average of approximately \$760 million. Weather-related insurance claims for Victoria 1990–2011 are shown in Figure 7. They also ran to >0.3% of gross state product three years running. In Queensland the costs of the 2010–2011 floods were around 2% of gross state product ([Hartley et al., 2011](#)) and resulted in a national flood levy on high income earners. According to ABARES, the impact of the 2010–11 floods on Australia’s agricultural production and exports was roughly \$2.3 billion ([ABARES, 2011](#)).

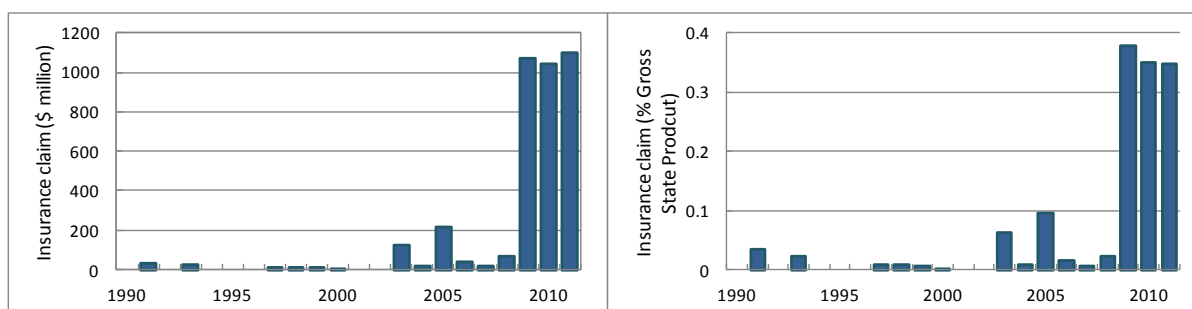


Figure 7. Weather-related insurance claims for Victoria 1990–2011. Damages in millions of dollars on the left and as a percentage of gross state product on the right.

Australian government funding for disaster mitigation and resilience 2005–06 and 2010–11 was \$182 million, whereas spending on disaster responses was 6,705 million (Table 2). This disparity in funding is continuing to grow.

Table 2. Australian Government funding for disaster prevention and recovery, 2005-06 to 2010-11 ([Productivity Commission, 2012](#))

	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
	\$m	\$m	\$m	\$m	\$m	\$m
Disaster mitigation or resilience	31	24	30	37	34	26
Natural Disaster Relief and Recovery Arrangements	69	104	18	292	106	6,116

Cost estimates from the insurance industry are often used, however these are a limited proxy for actual cost and are problematic in many ways ([Keating and Handmer, 2011a, b](#)). [Keating and Handmer \(2013\)](#) utilise a few full economic impact assessments of bushfire to conservatively estimate the current costs of bushfires to the Victorian agricultural and timber industries. They find that:

- Bushfire costs the Victorian agricultural industry approximately \$42 million per annum. Including business disruption the total cost to the Victorian economy is approximately \$92 million per annum.
- Bushfire costs the Victorian timber industry approximately \$74 million per annum. Including business disruption the total annual cost to the Victorian economy is approximately \$185 million per annum.

[Keating and Handmer \(2013\)](#) estimate that climate disasters cost the Victorian public sector approximately \$424 million per annum, accounting for direct expenditure in terms of output and asset investments only.

3.1.2 The science of rapid climate change

Observations, past climate reconstructions, and climate model output strongly suggest that anthropogenic is non-linear and step-like, with rapid shifts in climate means and extremes. This information is very important for adaptation because it can change the way it is costed, evaluated and implemented.

A version of this material with greater detail is in Appendix A.

Figure 4b shows the standard way of showing climate information as a smooth curve. Figure 8a shows the same raw data that was used to produce that smooth curve. Using the statistical methods for analysing rapid change described in Section 2.5, Figure 8b shows the same time series with a series of step and trends (bold dashes) and a non-linear line of best fit (dotted line). Instead of a smooth curve, this time series shows a staircase of more gradual trends punctuated by step-like changes.

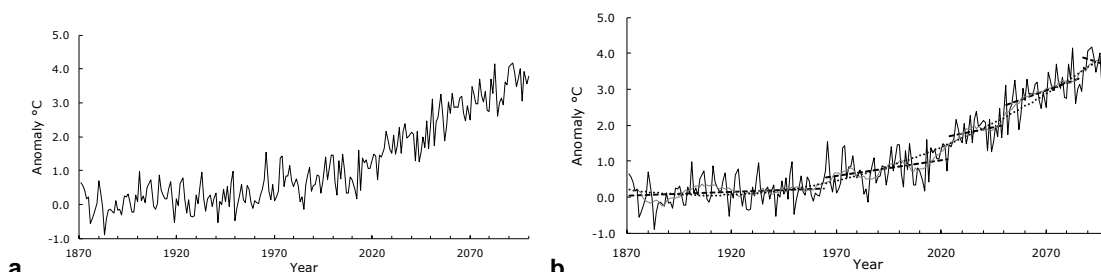


Figure 8. Single climate model simulation for south-east Australian minimum temperature (CSIRO Mk3.5 A1B T_{minAGW}) showing a) the mean, b) annual variability and c) mean, annual variability and step changes for a high emissions pathway.

The other important finding is that this data has been produced by a climate model simulating climate change over SE Australia. Of over 20 simulations looking at changes in maximum and minimum temperature every simulation showed multiple step changes occurring over the latter 20th and 21st century of up to 1.5°C for maximum temperature and up to 1°C for minimum temperature. About half of over 20 twenty rainfall simulations show similar step-like changes.

In the following paragraphs, we show that such changes are widespread in both observed and simulated time series of a range of important climate variables. This is an important finding with significant implications for adaptation planning. The smooth curve and series of step and trends shown in Figure 8b will produce different patterns of impacts resulting in very different economic outcomes as we will show in Sections 3.3.1 and 3.3.2.

Evidence for non-linear climate change

The process of anthropogenic climate change is described by two competing hypotheses ([Corti et al., 1999](#); [Hasselmann, 2002](#)):

1. Anthropogenic climate change occurs independently of climate variability; and
2. Anthropogenic climate change interacts with climate variability.

[Corti et al. \(1999\)](#) stated:

“A crucial question in the global-warming debate concerns the extent to which recent climate change is caused by anthropogenic forcing or is a manifestation of natural climate variability. It is commonly thought that the climate response to anthropogenic forcing should be distinct from the patterns of natural climate variability. But, on the basis of studies of nonlinear chaotic models with preferred states or ‘regimes’, it has been argued that the spatial patterns of the response to anthropogenic forcing may in fact project principally onto modes of natural climate variability.”

The first hypothesis supports a gradual climate response to forcing, but the second would produce distinct non-linear behaviour in climate variables. The key to deciding between these two hypotheses is in assessing climate behaviour over decadal time scales. Figure 9 shows a wide range of time series from observations around the world analysed using the step and trend methodology described in Section 2.5.

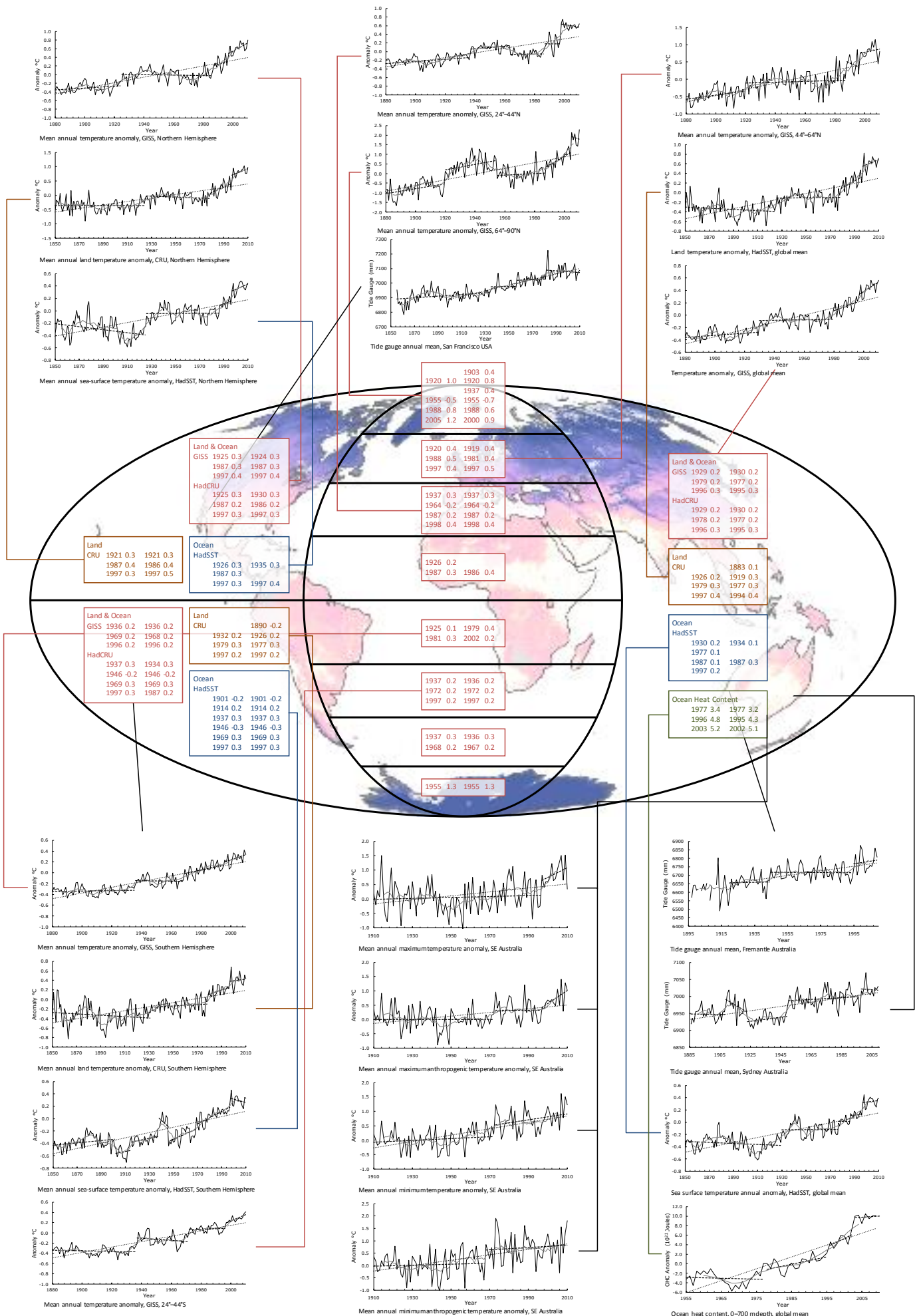
The tests show a clearly accelerating number of shifts over the latter part of the record.

Fewer shifts occur near the equator and more occur at higher latitudes. The most prominent of changes in temperature at the regional and global scale coincide with the 1997–98 ‘El Niño of the century’ ([Changnon and Bell, 2000](#); [Karl et al., 2000](#)). This registers as a 0.2–0.3°C step change within most of the GISS and Hadley data sets at the regional, hemispheric and global scales.

The timing of many of these changes coincide with extreme events or changes in decadal variability ([Tomé and Miranda, 2004](#); [Menne, 2006](#); [Ivanov and Evtimov, 2010](#); [Ruggieri, 2013](#)). Notable dates for average temperature changes in Figure 9 are 1936, 1968 and 1997 in the southern hemisphere and 1920, 1988 and 1997 in the northern hemisphere. The dates 1946 and 1976 also occur in some latitudinal average records.

In the northern hemisphere, a cooling episode in the mid-20th century interrupted warming ([Ivanov and Evtimov, 2010](#)). Unpublished analyses of temperature change of several USA states using the method of removing natural variability from temperature records as carried out for SE Australia ([Jones, 2012](#)), suggests this cooling was due to natural variability. Using this method, climate was stationary for most of the 20th century and anthropogenic warming temperatures in continental USA did not begin until 1988.

Figure 9 (opposite). Selected local, regional and global climate variables covering air and sea surface temperature, ocean heat content and tide gauge records. Statistically significant step changes to the 1% and 5% level analysed with the bivariate test (left) and STARS test (right) are shown with year and size of change between periods. Method of analysis described in Jones (2012).



3.1.3 The anatomy of rapid climate change

Rapid change can be identified at a number of points through the cause and effect pathway; affecting climate change itself, and increasing the likelihood of impact thresholds or system 'tipping points' being exceeded.

The previous sections show rapid changes in regional climates occurring as a series of step-change responses to external forcing. These may be occurring in combination with internally-generated climate variability. Here, we explore the history of these changes for Australia and the potential for future rapid change, particular those that affect climate extremes.

Rapid changes in impacts are often called thresholds or 'tipping points' and come in two basic forms. The first is a physical threshold that heralds a change in a system process or state, and the second is a graduated change in one or more measures that leads to some kind of planning or management response ([Kenny et al., 2000](#); [Pittock and Jones, 2000](#); [Schneider and Lane, 2006](#)). Rapid climate change will affect the magnitude and frequency of thresholds being crossed, so the dynamic between climate change and impact thresholds becomes important when considering impact costs and adaptation needs.

The contribution of how changing climate hazards may contribute risks to can be summarised as:

- Gradual change as part of a trend. Not as common as previously thought due to an over-reliance on the signal-to-noise concept.
- Step-changes expressed as rapid shifts in mean and variability. These may be associated with a regime change in decadal variability affecting mean and/or patterns of annual and seasonal variability (e.g., the Interdecadal Pacific Oscillation influence on ENSO). Model output shows they usually occur in the direction of the long-term externally-forced trend. Further investigation is required to survey the range of variables affected, regions of greatest change, frequency and magnitude of changes.
- Internally generated natural variability independent of climate change can produce clusters extreme events, or alternatively, contribute to relatively quiet periods.

A further rapid change not examined here is a large-scale 'climate shift' such as the Younger Dryas, the cooling event 8,300 years ago or the rapid increase in sea level at 14,500 years ago. This type of scenario was investigated by [Schwartz and Randall \(2003\)](#) who assessed its implications for security in the USA. These are thought to be rare, only becoming a risk at higher magnitudes of climate change.

The main types of climate variable likely to be associated with rapid shifts are shown in Table 3.

Table 3. Climate variables potentially associated with greenhouse-induced rapid changes with evidence and notes.

Event	Evidence for step change		Notes
	Observations	Models	
Extreme heat/heatwaves	Southern Australia (since 1997), global evidence circumstantial (mean annual Tmax change), continental US	SE Australia, Melbourne region (monthly max temp), every run	Northern Australia, there is some evidence the high P has suppressed Tmax increases (Alice Springs)
Fire Danger (FFDI Days high–catastrophic)	Victoria (1998, 2002) based on the average of 9 site records	SE Australia, Melb region, transfer function using Tmax and P, some runs	Data from Lucas (2009) , with inhomogeneities in wind speed adjusted and poorer parts of records omitted
Mean temperature	Every region	SE Australia, global mean, every run	
Mean rainfall	SW WA, some individual streamflow records SE Australia. Nile, Yangtze historical records	SE Australia, Melb Region, about 50% of models	Some evidence that models are less hydrological sensitive than observations
Extreme daily rainfall	SW WA (1968, downward), circumstantial evidence associated with mean changes	Not checked, using mean as a proxy, likely if mean rainfall steps	Checked for trend, so likely to be non-linear if associated with shifts in mean
Flash flooding	Little evidence of non-linearity, stats hard to pin down	Not checked	Models show increases in convective strength and extreme events on a per event basis
Wind speed	Some evidence of decadal variability	Not checked	Mean may decrease in many regions and extremes increase
Tropical cyclones	Some evidence of decadal variability in numbers and intensity	Not checked	Wind speed and central pressure has been checked for trend, little evidence on numbers
Extreme cold	Linked to step changes in min temp, decreasing	SE Australia, Melbourne region (monthly min temp), every run	Numbers decreasing
Extreme seasonal rainfall	Some evidence of wetter summer rainfall in N Aust with increasing temperatures	Mean shows non-linear behaviour	Perhaps falls of tropical origin are increasing and mid latitude origin are decreasing
Sea surface temperature	Widespread in ocean basins	Not checked	Changes in air temperature over land are most likely affected by non-linear changes in SST
Ocean heat content	Widespread at ocean basin and global scale	Not checked	Models contain the physics likely to reproduce such changes
Sea level	Ubiquitous in tide gauge records (20–30 mm)	Not checked	Models contain the physics likely to reproduce such changes

Tmax – maximum temperature, Tmin – minimum temperature, SST – sea surface temperature.

The potential for step changes to cause a greater number of climate induced 'shocks' has implications for how future risks and hazards should be managed and costed. Rapidly changing extreme events can lead to unanticipated levels of stress occurring in a relatively brief period.

Coping ranges and thresholds

The coping range of climate ([Hewitt and Burton, 1971](#)) is described by the IPCC as the capacity of systems to accommodate variations in climatic conditions ([Smith et al., 2001](#)). It includes the range of climate variability that covers qualities that span thriving in to barely tolerating climatic conditions (Figure 10). The core of the coping range contains beneficial outcomes. Towards one or both edges, outcomes become negative but tolerable. Beyond the coping range, the damages or losses are no longer tolerable and denote a vulnerable state; the limits of tolerance describe a critical threshold. Levels of vulnerability mark the size of the adaptation deficit. A coping range is usually specific to an activity, group and/or sector.

This is a conceptual model for understanding changing risk (c.f., [Morgan et al., 2001](#)) that provides a suitable template for understanding the relationship between changing climate hazards and society ([Carter et al., 2007](#)). The concept of the coping range incorporates concepts of current and future adaptation, planning and policy horizons, and likelihood ([Downing et al., 1997](#); [Jones, 2001](#); [Yohe and Tol, 2002](#); [Willows and Connell, 2003](#); [UNDP, 2005](#)). It can sometimes be used operationally, but often remains conceptual because of difficulties with measuring phenomena like critical thresholds in complex situations.

At the institutional scale, the coping range can be thought of a measure of socio-economic capacity after [Yohe and Tol \(2002\)](#). Large-scale critical thresholds may involve irreversible damage to an iconic or important natural system such as the Great Barrier Reef or Kakadu National Park, or be significant enough to contribute to dangerous anthropogenic interference with the climate system ([Schneider and Lane, 2006](#)).

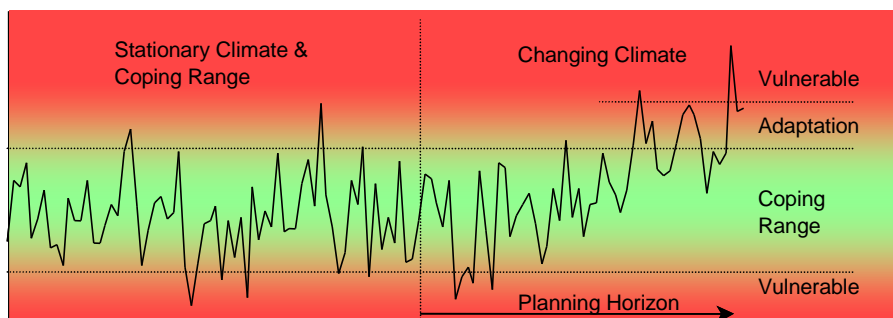


Figure 10. Coping range showing (a) the relationship between climate change and threshold exceedance, and (b) how adaptation can establish a new critical threshold, reducing vulnerability to climate change ([Jones and Mearns, 2005](#)).

This project looks at the thresholds that mark where risks cross domains. Such thresholds may affect several institutions at once. The values at risk held within the broader socio-economic system will affect institutional outcomes if they are 'owned' by that institution – either by being a formal responsibility or part of institutional practice and goals. For example, if profits are effected across and industry sector, industries will respond and may act to prevent such losses in future. Some risks may be 'un-owned' in that they are widely held to be of value, but are not included in institutional

responsibilities, or they are written into institutional rules but are latent and not acted on. Many such risks are environmental or social and belong to the 'commons'.

Most of the thresholds assessed in the literature are activity-based but some are system-based. [Yohe and Tol \(2002\)](#) suggest an approach based on vulnerability as a function of exposure, sensitivity and adaptive capacity. The determinants of adaptive capacity they tested for expanding the coping range included technology, resources, institutions, human capital, social capital, risk spreading processes, managed information and attribution processes. The measures they used were designed to assess options against each other to test their relative effectiveness.

Other coping ranges are judged according to a physical limit. For example, [Jones and Page \(2001\)](#) constructed two critical thresholds for the Macquarie River catchment in Australia for irrigation allocation and environmental flows. The probability of exceeding these thresholds was a function of both natural climate variability and climate change, and in 2008, both thresholds had been exceeded in the Millennium drought. This may have been due to non-linear interactions of climate change and variability. For ecosystems, such as the Great Barrier Reef, measures of ecological function are being proposed and developed ([McCook et al., 2007](#); [De'ath et al., 2008](#); [Olsson et al., 2008](#); [Bennett et al., 2009](#)).

This project is taking a more institutional focus than [Yohe and Tol \(2002\)](#) but similarities remain. The elements of adaptive capacity they list are all important as are the practical factors of feasibility and effectiveness. However, here institutional structures are seen as major determinants as to how these factors can be organised into a framework that can accommodate both bottom-up (location specific, actor and community-based) with top-down (macro-economic, policy and governance) factors.

Rapidly changing extremes

Rapidly changing extremes are the major driver of vulnerability to climate change, and the costliest if not adapted to. Assessing the distributional aspects of extremes over time provides a picture of potential impacts and adaptation needs. An important assumption that can be drawn from the structure of the coping range shown in Figure 10 is that the relationship between extremes and threshold exceedance is an important determinant of vulnerability.

Most of the range of a single climate variable is likely to be within the coping range in all but very narrowly-adapted systems. That means if a rapid change occurs, most of the distribution will still fall within the coping range. For activities widely distributed across climate gradients (such as agricultural production systems, adaptation analogues), an example of the same or a similar activity being carried out in a similar range of climate will be within reach for those affected, subject to adjustment costs for those carrying out the adaptation ([Quiggin and Horowitz, 2003](#)). An example of this is the expansion of cropping at the expense of grazing in formerly wetter areas of Victoria during the 2000s, increasing profitability per hectare.

In sectors where markets are active, such adaptation is likely to be market-led. Under the assumption of gradual change, it is easy to assume that markets will have time to adjust to such changes. Under rapid change, these assumptions may be unsustainable.

Also, the direct transfer of adaptation analogues (like activity for like climate) may not work if patterns of extremes unfamiliar to everyone emerge. This could be the case for very extreme heat, rainfall intensity, severe storms or more intense swings between

drought and flood. Step changes will also threaten systems with a limited adaptive capacity (such as fragmented ecosystems in highly-altered landscapes) because of their limited ability to respond.

The limiting factor for most systems is where events exceed thresholds at an increased rate and magnitude. For a system close to a critical threshold, this can have significant impacts. For systems a long way from such thresholds, a small number of shifts may occur, then one more step change produces serious results. Sensitivity to change is a function of how close a system is to critical thresholds ([Katz and Brown, 1992](#); [Keller et al., 2004](#); [Wilmking et al., 2005](#)). This is important information for adaptation planning because rapid shifts in climate can move a system towards, or even across, a threshold much sooner than anticipated under gradual change.

These relationships are shown in Figure 11a and b, where recent changes in daily and monthly maximum temperature for Laverton are illustrated. This station is used because it is a high-quality temperature station close to an urban centre that is still classified as rural, so is free of the urban heat effect. This record is divided into three periods; 1944–1972, 1973–1996 and 1997–2011 – marking the known stationary and first and second non-stationary periods between step changes.

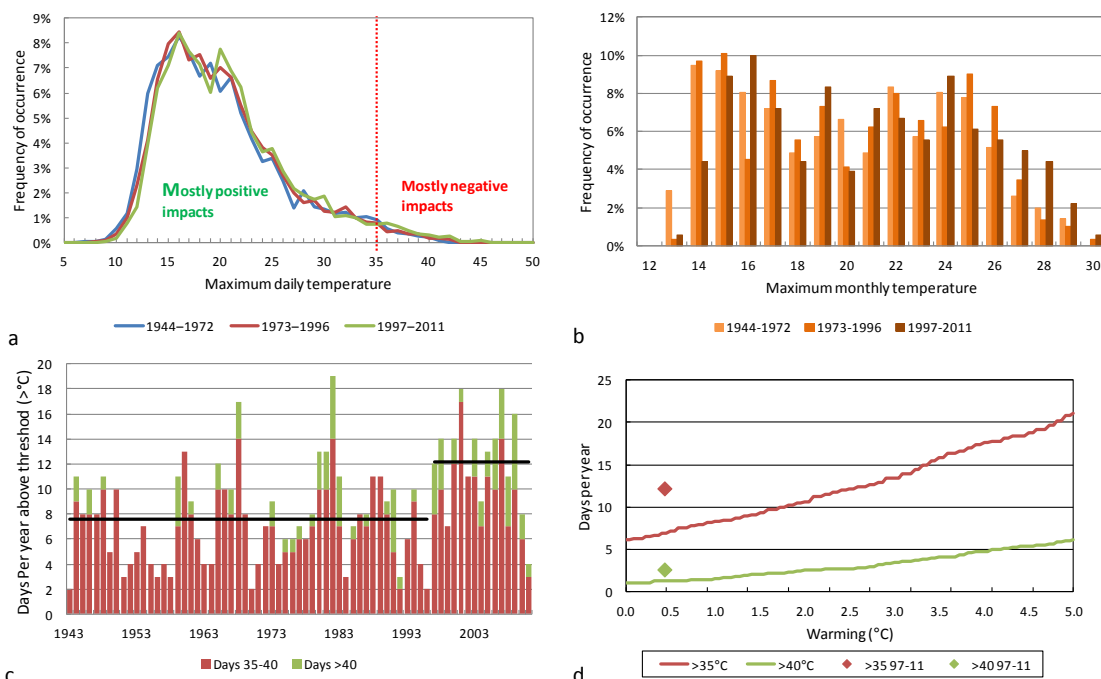


Figure 11. Frequency distribution of a) daily and b) monthly temperature at Laverton for the period 1944–1972, 1973–1996 and 1997–2011. Number of days c) from 35–40°C and >40°C 1944–2011 with the average of days above 35°C shown as black lines before after 1997; and d) scaled as a function of temperature from a baseline of 1974–1996, shown with the 1997–2011 average from c. Note that the averages from the periods 1944–1996 and (c) 1974–1996 (d) are slightly different.

Most of the change in range is associated with positive impacts due to decreases in cold temperatures reducing cold stress and warmer average daily temperatures leading to a more comfortable outdoor environment. Such changes can readily be adapted to. However, for the two thresholds of 35°C and 40°C associated with heat stress, increases are notable. The first step-change event in 1968–73 mainly affected minimum temperature and partially masked a potential increase in maximum temperature due to higher rainfall at the time.

However, the second step change in 1996–1997 involved an increase in mean maximum temperature of about 0.5°C from the preceding period and saw an increase in days above 35°C from 8–12 per year.

Figure 11d shows increases in days above 35°C and 40°C as a function of increases in mean scaled up from a baseline of 1974–1996, and contrasts it with observed days above 35°C and 40°C from 1997–2011 (note that the two baseline periods are slightly different). This scaling method is commonly used and was the same site data used in the Garnaut Review estimate of heat deaths (Bambrick et al., 2008) and in recent communications on climate change and human health from the Climate Commission (Hughes and McMichael, 2011).

The observed frequency of extreme temperatures has increased beyond the number that would be estimated by scaling them according to changes in the mean, emphasising the potential for extremes to change faster than the mean.

Economic implications

Rapid climate change calls into question existing patterns of settlement, may make some current methods of production, consumption and transport no longer viable, and pose threats to the health and welfare of many citizens. Such changes would also require a fundamental reshaping of infrastructure.

Such a pervasive threat poses a major challenge to economic methods and models attuned to the analysis of more limited problems. While economic models are simplifying devices, the basic model of neoclassical economics is very simple indeed. Its ontology is sparse, containing two forms of economic organisation: the market and the government, two types of goods; private goods and public goods, and two agents; rational utility-maximising individuals and profit-maximising firms. Its starting assumptions are many, and chosen to derive the mathematical results in which the market delivers the optimum. These assumptions include complete markets and perfect foresight, diminishing returns to scale, agents that only interact through the market and a given structure of technology and of goods.

In such a model, the best economic outcome can be achieved through the market, with lump sum transfers by governments required to make this also the social optimum. No economist presumes that this is an accurate description of the real world, but many do take it to be a reasonable starting point. If one starts from this model and makes the assumption of gradual climate change, the task of adaptation policy is relatively straight-forward. Autonomous action by private individuals and firms through markets is likely to deliver most of what is required for adaptation to gradual climate change.

As a result, the main priorities for adaptation policies are to:

- reduce the barriers to the effective operation of markets, which would also deliver benefits in current climate conditions;
- improve the availability of information to market participants;
- increase the effectiveness of government in its areas of responsibility; and
- deal with the impact of climate change on the disadvantaged through the tax and transfer system.

Given that knowledge of the impact of gradual climate change will increase over time, there is little case for undertaking long-term, costly initiatives to shape adaptation in

relation to an uncertain future. This is a brief summary of the conclusions of the Productivity Commission's recent draft report (2012) on adaptation.

An important exception to this general pattern is found in some of society's approaches to sudden (or at least to events that appear sudden) events with negative impacts – such as climate extremes (for more detail on this point see IPCC (2012a, b)). This was recognised in the Productivity Commission's report, which highlighted the important government role in emergency management as a fundamental way of dealing with change and the manifestation of that change through extremes.

3.2 Gradualism: current approaches to assessment

Current methods of assessing climate impacts and adaptation are out of step with the evidence for rapid change present in the previous three sections. Instead, they are formed by very strong narratives of gradual change, pervasive through both the science of climate change and the economics of adaptation. In the following sections, we look at the structure of these narratives and their origins, their influence on science and economics, and summarise current adaptation policy in Australia.

3.2.1 Current narratives and their influences

Gradualist narratives informing adaptation are developed from scientific narratives, which are socially-constructed accounts of how the climate changes. This section introduces adaptation narratives and describes a model that outlines how scientific knowledge contributes to the building of those narratives.

Narratives are accounts of events with temporal or causal coherence that can be constructed for a purpose ([László and Ehmann, 2012](#)). Narratives can be linked to individuals and organisations, and include institutional and cultural narratives. They are an innate property of the expression of mind in communication with one's-self or another; and are a "tool or process for making sense of events" ([Gephart Jr, 1991](#)) and have a strong role in creating social legitimacy. At the core of narratives is the use of language:

"Many people believe that language is a tool used to describe and report on reality. Language is not only content; it is also context and a way to recontextualize content. We do not just report and describe with language; we also create with it." ([Boje et al., 2004](#))

Narratives can be spoken, written, and expressed visually or physically and can be presented formally or informally. They include storytelling, fables, myths and legends, songs, paintings and different forms of theatre. In organisations, narratives can be conveyed through informal conversations between actors or more formally communicated through presentations or documents. Narratives are iterative in nature and can alter with the teller and with time as they reconstruct events as they occur in order to find their meanings ([László and Ehmann, 2012](#)). Meanings may change with time, memory and context.

Scientific narratives

Scientific narratives are important tools for explaining the cause and effect sequence of processes and phenomena interpreted from scientific theory. They are also key tools in framing how science is viewed within a broader social and cultural context, contributing to narratives of cultural origins and identity and framing themes around issues such as progress and risk ([Shackley et al., 1998](#); [Edwards, 1999](#)). Scientific narratives can also

be used to manage conversations about science: *by appropriating the labels available to describe a certain phenomenon, one also appropriates what sense can possibly be made of it* ([Näslund and Perner, 2012](#)).

Recent literature has explored how scientific narratives of climate change are influencing broader social narratives, especially via framing effects ([Jasanoff, 1996](#); [Hulme, 2009](#); [Jasanoff, 2010](#); [Viehöver, 2011](#)), but work on the first step of narrative building – how climate science is developed into narratives for both formal and informal settings – has been limited.

For narratives informing adaptation to climate change, scientific narratives describe the way in which climate change is expected to change and by how much (*e.g.*, [Edwards, 1999](#)). These narratives also inform climate scenario construction and, in turn, will inform the construction of adaptation methods. They will also combine with narratives of climate experience in the general community to inform the adaptation process. The initial scientific narratives of climate change constructed by the scientific community are critically important in shaping how subsequent narratives informing adaptation are constructed. To date, this conversation has been dominated by the IPCC through its carefully-constructed language on uncertainty delivered to policy-makers ([Viehöver, 2011](#)).

The model we are using to explain this sequence of narratives is shown in Figure 12. Expert scientific knowledge is shown as being constructed through general scientific narratives. Scientific knowledge becomes robust through review, criticism, modification and consensus-building. Discipline-based narratives such as climatology, build on these narratives but also develop their own modifications informed by a specialist community of practice. These modified narratives inform broader public narratives of how climate changes. They also contribute to the development of methodologies for assessing and managing risk.

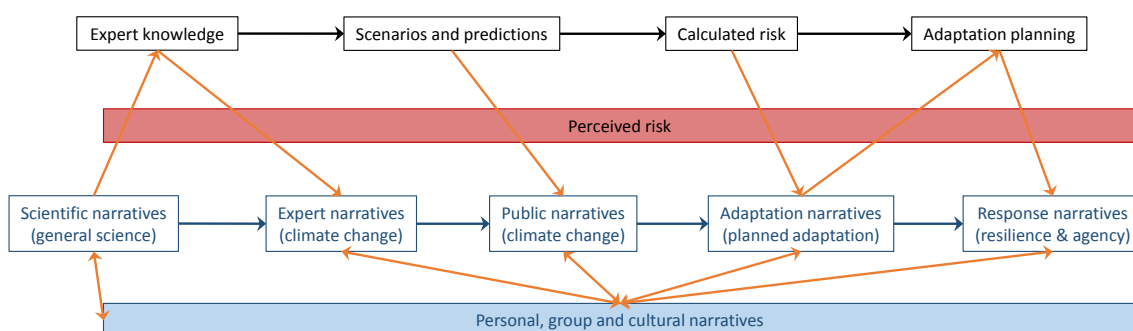


Figure 12. Conceptual model of the development of expert knowledge and narratives informing adaptation.

A recent literature has critiqued the framing of science communication to policy-makers and the public by bodies (such as the IPCC) as carrying specific frames that influence public narratives and the perception of risk ([Hulme, 2009, 2011](#)). In particular, narratives of risk and catastrophe have proven to be politically divisive. They are charged with producing decision paralysis if not accompanied by enabling narratives that provide potential solutions ([Hulme, 2008](#); [Risbey, 2008](#)). While most authors have concentrated on how scientific information is being framed to inform decision-making and public opinion ([Patt and Schrag, 2003](#); [Kandlikar et al., 2005](#); [Swart et al., 2009](#); [Hulme, 2011](#)), few have assessed whether the basic narratives of climate change

accurately reflect the weight of scientific evidence ([c.f., Beven, 2002](#)). This does not include contrarian narratives that challenge the basic science.

A distinction needs to be made between the straightforward communication of science and the communication of scientific information for risk, which contains a specific value component ([Jones, 2011](#)). This distinction has not been recognised in the IPCC uncertainty guidance material ([Mastrandrea et al., 2010](#)). Adaptation narratives need to be informed by the decision-making context within which climate risks are assessed, and can only be addressed by having experts working with decision-makers in order to develop a comprehensive understanding of a specific problem-solution process. This process is one of *innovation*.

Types of adaptation narratives

Adaptation narratives can take on many forms. Because different stakeholders and contexts may be involved in adaptation narratives, collaborative narratives that blend different narrative types are often developed. For example, scientists and community groups may collaborate to create a new narrative that incorporates narrative elements from a range of sources. This is *both a product and a manifestation of the complex process of (shared and confronted) meaning* ([Altopiedi and Lavié, 2006](#)), negotiated through a series of dialogues.

Types of narrative used in adaptation include:

- scientific;
- institutional;
- collaborative;
- community;
- personal; and
- cultural.

Two aspects that adaptation narratives aim to address are:

1. the transferral of ideas to action; and
2. the responses at an individual/institutional level to an aspect of adaptation.

The first aspect is in the translating of problem identification into a common understanding so that actions can be implemented. This narrative bridges the route between scientific paradigm and adaptation methodology, and is often achieved by working with the multiple actors in order to creatively explore the solution.

The second aspect concerns the stories that relate people's own responses to climatic impacts and other aspects of change. This is a complex area as these narratives relate strongly to identity, culture and perceptions of risk and are context specific. They provide the social construction within which decisions may be applied, and also inform the nature of responses to future climate events. For example, a community that believes itself to be resilient and self-reliant is more likely to respond proactively, contrasted to a community that believes itself to be vulnerable.

Institutional narratives are a key driver for understanding the rules and culture that influence both individual and institutional responses to adaptation. The role of institutions in developing and communicating scientific narratives, and how adaptation narratives are and can be used, is an important issue that requires further development.

3.2.2 Standard assessment methods and gradualist narratives

The gradualist narrative is the foundation of standard assessment methods for climate change. This section describes how that narrative is being applied and the influence it has on assessment methods.

The main areas of influence on scientific narratives that subsequently shape adaptation assessments are:

- assessment guidelines and how they have evolved;
- the use of the STNM to assess, attribute and communicate climate change;
- the focus on forecasting techniques using the signal-to-noise model to develop likelihoods of mean change in climate; and
- the communities of practice that have developed around climate modelling, IPCC assessments, and impacts and adaptation assessments.

Development of impact, vulnerability and adaptation assessments

Until recently, adaptation methods have been constructed largely along scientifically rational lines rather than being informed by the decision sciences, such as organisational theory and psychology.

Formal guidance for adaptation planning was originally published by the IPCC in 1994 ([Carter et al., 1994](#)). The original seven-step method, now more commonly-known as the standard method ([Carter et al., 2007](#)), has since been expanded and modified by many others ([Parry and Carter, 1998](#); [Willows and Connell, 2003](#); [UNDP, 2005](#); [AGO, 2006](#)). It generally follows a predict-then-act sequence of assessment ([Dessai et al., 2009](#); [Hulme, 2011](#)).

The current standard framework used in Australia is a risk assessment approach developed by the former Australian Greenhouse Office ([AGO, 2006](#); [Preston et al., 2007](#)) based on the ANZ risk management standard ([Standards Australia and Standards New Zealand, 2004](#)). The framework relies heavily on climate projections generated by CSIRO ([Whetton et al., 2005](#); [CSIRO and BoM, 2007](#); [Whetton, 2011](#)). Whetton et al. (in press) describe the recent history of climate scenario development in Australia.

The mainstay of impact assessment to now has been time slice experiments. Climate scenarios are constructed to represent a change in mean climate at a future date (2030, 2050 and 2070 are all common). These may be combined with scenarios of changing population, economic or other environmental conditions. These mean changes are used to scale existing climate records of up to a century or more in length, providing comprehensive assessments of climate change plus variability ([Jones, 2004b](#); [Chiew et al., 2009](#)). Scaling future changes by observed variability is assumed to represent likely future variability as a first approximation ([Chiew et al., 2008](#)). Changes in impacts extrapolated between now and the time slice date are used to estimate the gap between current coping capacity and what may be required in future. This extrapolation is generally assumed to proceed gradually.

Narratives of abrupt climate change do exist in the scientific literature and are widespread ([Alley et al., 2003](#); [Hulme, 2003](#); [Schwartz and Randall, 2003](#); [Schneider, 2004](#); [Arnell et al., 2005](#)) but with a few exceptions, have not become mainstream in impact and adaptation assessment. Abrupt climate change is also considered to a low probability event, becoming more likely over time with high rates of emissions. Such events are therefore framed as requiring a highly precautionary stance, mainly

informing the need for greater investment in mitigation ([Alley et al., 2003](#); [Weitzman, 2007a](#)).

Programs are now in place to develop decadal-scale forecasting, an area where predictability is considered to be low ([Hurrell et al., 2009](#); [Murphy et al., 2009](#); [Collins et al., 2011](#)). Predictability of decadal change is linked to the reproducibility of results over multiple simulations. The main methods being proposed to predict decadal climate are to use the STNM to derive the most likely decadal mean change analysed as a gradual signal.

Although the STNM contributes to a wide range of analytical and techniques and communication tools, its use continues to perpetuate the narrative of gradual climate change.

Impacts and adaptation

The widespread assumption that adaptation is a gradual process is captured by the following statements:

- *Within limits, the impacts of gradual climate change should be manageable.* www.pc.gov.au
- *Therefore, climate change adaptation can be understood as: (a) adapting to gradual changes in average temperature, sea level and precipitation.* www.prevention.web
- *Gradual climate change allows for a gradual shift in the mix of crops and to alternative farming systems.* www.ers.usda.gov

The difference between current and future rates of adaptation caused by changing climate is known as the adaptation deficit or adaptation gap ([Burton, 2004](#); [Burton and May, 2004](#)). [Burton \(2004\)](#) identifies two types of adaptation deficit; the deficit to current climate variability and the deficit to climate change. The size of the latter deficit is often proportional to the magnitude of climate change, although non-linear climate-impact relationships, and system thresholds or 'tipping points' may accelerate the adaptation deficit relative to climate change.

Measuring the adaptation deficit as a factor of climate change, ignoring the current adaptation deficit, is consistent with the definition of climate change mandated by the UNFCCC, but may not be the most useful for undertaking adaptation. A true index of adaptation needs would cover all weather and climate-related hazards ([Bass, 2004](#)) incorporating climate change and variability in a whole-of-climate approach ([Jones, 2010a](#)). Such a measure would require the mainstreaming of adaptation into sustainable development building within both the social and ecological aspects of adaptation (*e.g.*, [Yohe et al., 2007](#)). A further option is to measure adaptation as the degree of innovation required for coping with variability and change ([Bass, 2004](#)). This is the most useful path to take, but the most difficult to measure.

Most impacts and adaptation studies are conducted over a small to moderate sized region, natural or human system, sector or activity; largely because of the significant spatial and temporal heterogeneity in impacts and for adaptation options. Most adaptation policy therefore covers adaptation actions at these scales.

The main ways to combine information from multiple impacts are:

- to combine the results from diverse studies ([Preston et al., 2006](#); [Hennessy et al., 2007](#));

- to conduct a set of studies with common inputs ([Garnaut, 2008](#)); or
- to construct and run an integrated assessment model.

Issues such as inconsistent scenarios and underpinning assumptions cause difficulties with the first case, the need for coordinated funding limit the second, and compromises in detail limit the conclusions that can be drawn in the last case. For these reasons, obtaining aggregated findings to assess potential adaptation needs at the institutional, state or national scale is difficult. Even though individual adaptation assessments are becoming more sophisticated and are using scenarios of social and economic change that are more tailored to the needs of users, the aggregation problem remains. This project takes a different approach to the modelling approach, instead using the IAD framework to address institutional arrangements and values with respect to adaptation (as described in Section 2.3).

3.2.3 Orthodox economics of impacts and adaptation

The main tool used to assess the economics of impacts and adaptation is cost-benefit analysis (CBA) modified to take account of uncertain future climate risks over long time frames.

Orthodox economic thinking on climate change adaptation is centred on the optimality criterion, where investment and action on adaptation should maximise benefit to society. [Osberghaus et al. \(2010, p. 837\)](#) state “the sum of all marginal benefits from public adaptation should equal the marginal costs of public investment.”

[Heuson et al. \(2012\)](#) delineate how optimality in the investment decision is ideally achieved at all levels:

- Micro level – the maximisation of net benefit for a single adaptation measure;
- Single problem, several measures – the measure or group of measures that provide the greatest net benefit for a single problem (e.g., bushfire);
- Several problems, many measures – the group of measures that provide the greatest net benefit across multiple problems (e.g., a sector or region); and
- Macro level adaptation – investment is optimised across the whole economy, carried out in conjunction with mitigation.

In some instances, specific adaptation measures may be deemed to be sub-optimal because the marginal benefits of avoided impacts are less than the marginal costs of the corresponding adaptation investment. In these instances, resulting damages would be endured rather than addressed ([Osberghaus et al., 2010](#)).

A further aspect of optimal adaptation is timing. In sectors that are able to respond quickly and have relatively low capital-intensity, timing of adaptation is less important. However, when adaptation is time-consuming, possibly requiring many years of transition, selecting the optimal timing for investment becomes important. Optimal timing of adaptation attempts to optimise over three factors: 1) change in adaptation cost over time, 2) any immediate or short-term co-benefits of adaptation, and 3) long-term irreversibility of the adaptation measure ([Heuson et al., 2012](#)). Timing of adaptation with respect to the potential timing of risk is also a factor to be considered.

While costs, benefits and timing can be easily conceptualised, in practice it is difficult to impossible to determine specific climate adaptation costs at any level above the micro scale. This is partially because many adaptation initiatives are taken within the context of wider social, economic and environmental conditions, which may be more influential than the climate change component. Hence, separating out the climate adaptation aspect of a decision is not straightforward ([Agrawala and Fankhauser, 2008](#)). In many

cases, the large uncertainties inherent in projecting future costs and benefits also preclude optimisation.

The theory of optimal adaptation assumes to some degree that a “comprehensive catalogue of potential damages and adaptive measures” ([Ackerman and Stanton, 2011, p 16](#)) can be utilised for decision-making, which is simply not the case.

The orthodox approach described here is profoundly informed by the scientific narrative of gradualism (described in Section 3.2.1), and has the same cultural origins. It also has embedded in it the values of ‘objectivity’ and ‘fungibility’, as costs and benefits across the same comprehensive catalogue can be readily compared.

Gradual change is also very attractive to economic theorists and modellers because it is analytically convenient to assume that change happens gradually. It also lends itself to favour market-based autonomous adaptation over government intervention.

Public and private adaptation

The case for government intervention in adaptation is routinely justified on the basis of market failures. Mitigation of climate change via reductions in greenhouse gas emissions reduces overall climate change risk. This reduction in risk is freely available to everybody on the planet, therefore mitigation produces a ‘public good’. Economic theory purports that public goods are market failures ([Aaheim and Aasen, 2008](#)) and are produced at below-optimal quantities because individuals can benefit from the actions of others without having to take action themselves. As such, the economic case for government intervention in the case of mitigation is well-established.

Adaptation, on the other hand, often produces private goods because adaptation actions generally reduce risk to a certain group. Economic theory suggests that private goods (adaptation) will be produced by the people who benefit from them, therefore the case for government intervention is theoretically less clear ([Agrawala and Fankhauser, 2008](#); [Hallegatte et al., 2011](#); [Productivity Commission, 2012](#)). Despite this, government interest in adaptation is expanding in an effort to identify where public funds would be most beneficial.

[Aaheim and Aasen \(2008\)](#) identify three broad categories where government intervention is warranted:

- **Public goods:** adaptations that produce benefits for multiple economic actors in a non-exclusionary way are likely to be under-pursued privately;
- **Large transaction costs:** required adjustments may be so expensive for autonomous actors that they will only occur with government intervention; and
- **Immobility:** the factors of production are not always mobile, and may be located in climate-sensitive areas. Examples are fisheries and tourism.

Gradual change has the benefit of providing actors with sufficient time and clear, incremental market signals that allow for adaptation – either to a new steady state or continuously. Because the change is gradual, costs accrue smoothly. Under such change, the role for government as demonstrated by the [Productivity Commission \(2012\)](#), is small relatively to autonomous market adaptation, which is preferred in orthodox circles as it is considered to be optimal.

Equity is a key concern for all policy-makers and is a central theme for climate change adaptation. The neoclassical economics view is that equity issues in climate adaptation ought to be dealt with via the welfare and taxation system ([Dobes and Bennett, 2009](#);

[Productivity Commission, 2012](#)). This way, relative prices are not distorted and there is transparency in government support ([Osberghaus et al., 2010](#)).

This approach is favoured by the Productivity Commission's draft report on barriers to climate adaptation ([Productivity Commission, 2012](#)). However, this approach is not always possible and/or adequate. [Osberghaus et al. \(2010\)](#) describes the use of heat-wave shelters for the homeless that are increasingly being used in the US. This example shows the importance of considering equity in context, rather than just relegating it to the social welfare and taxation sphere – especially for homeless people beyond the reach of both. For policy-makers, economics cannot determine how equity should be treated in climate change adaptation policy because it is an ethical question ([Osberghaus et al., 2010](#)). However, economic analyses can assess how costs and benefits (welfare) may be distributed between different groups in society.

Neoclassical methods for valuing adaptation

The consensus in orthodox economics is that an adaptation initiative ought to be pursued if its expected marginal cost is equal to, or less than, the expected marginal benefit. Hallegatte et al. (2011, p. 7) state that the “cost of adapting to climate change is the sum of investment costs and operating costs linked to the establishment of adaptation strategies.” Climate change adaptation would not totally ameliorate the impacts of climate change, but the goal is to optimise climate change adaptation investment over time at no net cost ([Hallegatte et al., 2011](#)).

[UNFCCC \(2009, p. 3\)](#) defines the costs of adaptation as “the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs” and the benefits of adaptation as “the avoided damage costs of the accrued benefits following the implementation of adaptation measure”. In this context, the costs and benefits are not only financial but consider wider societal impacts.

Many theorists measure the benefit of adaptation in terms of climate change damages avoided ([World Bank, 2010](#)). The benefit of adaptation is calculated by estimating the total damage costs of climate change without the adaptation, then deducting the estimated damage cost avoided by the adaptation (because it is unlikely that the total damage costs of climate change will be avoided). Co-benefits that flow from adaptation measures are also ideally estimated and included as benefits ([Huq and Reid, 2004](#)). Estimating both costs and benefits of adaptation is complicated by the difficulty in assigning a dollar value to intangible assets such as ecosystem services; e.g., the cooling benefits of urban forests and flood mitigation services of wetlands.

[Dobes \(2012\)](#) argues that the damage-cost avoided approach to benefit estimation is fundamentally problematic because it is, at best, “a very poor proxy for the conceptually correct measure of ‘willingness to pay’ (WTP) for adaptation measures, or the converse of ‘willingness to accept’ any negative aspects associated with climate change” (Dobes 2012, p. 6). He proposes a series of choice modelling studies to estimate willingness to pay to address climate disaster damages in different regions. While this critique identifies important issues, WTP estimates are themselves contentious ([Venkatachalam, 2004](#)). This places the value of adaptation in the hands of individuals within the market.

Another literature dealing with sustainable development addresses adaptation from a general welfare point of view, valuing the benefits of adaptation as the avoided damages to both current and future climate ([Smit et al., 2000](#); [Huq and Reid, 2004](#); [Adger et al., 2005](#); [Ayers and Huq, 2009](#)). Thus, the value of adaptation differs according to how it is framed in terms of economics and ethics. Institutional values are

an important framing for such considerations; for example, financial institutions will have a different emphasis on values from those concerned with social justice.

Modelling costs and benefits

Top-down economic models assume that the climate variability experienced over time will average out to a smooth change in costs; this shapes the understanding and perceived value of the economics of adaptation ([e.g., Ackerman et al., 2009](#)).

Establishing an accurate estimate of the costs of climate change impacts is difficult, as top-down (macro-economic) and bottom-up (micro-economic) costs need to be combined. This is a problem of ‘apples versus oranges’ that challenges all economic costing methods, not just climate change. Macro-economic costs tally net impacts across whole sectors, while micro-economic costs assess individual impacts. Aggregating individual impact costs to estimate whole of economy costs is a considerable challenge.

Top-down approaches utilise downscaled estimates from Global Integrated Assessment Models (which model the global climate-economy system). Bottom-up approaches utilise local or regional climate projections and estimate impacts; then with local decision-makers and stakeholders, evaluate potential adaptation options economically ([Heuson et al., 2012](#)). While the top-down approach can utilise available global models and thus can integrate spatially, they have been criticised their simplified economic models omit relevant costs. Furthermore, they lack local spatial or temporal detail, especially of climate extremes, so underestimate impacts ([Ackerman et al., 2009](#); [Füssel, 2010](#)). Bottom-up studies, are better at capturing important local and regional conditions relevant to decision-making at the local scale but are difficult to integrate at larger scales ([Heuson et al., 2012](#)).

Many economists ([e.g., Dobes, 2012](#)) nominate CBA as the most appropriate evaluative procedure for making specific adaptation decisions. The merits and limitations of the CBA methodology for climate change adaptation is an increasingly debated topic. The most significant challenge relates to how we measure expected costs and benefits under compounding climate-related uncertainties. Another key issue relates to how ‘benefit’ is defined and estimated. Other theorists such as [Hallegatte et al. \(2011\)](#) argue that multi-criteria analysis is more able to systematically incorporate issues such as equity.

CBA is a tool that is used to systematically “organise, appraise and present the costs and benefits, and inherent trade-offs of projects taken by the public sector authorities” ([Moench et al., 2007](#)). CBA calculates expected net present value by summing the probability weighted set of all possible outcomes. Traditional CBA assumes that the probability of each occurrence is known – however this assumption can be modified for a range of situations.

CBA has both adherents and detractors. [Dobes and Bennett \(2009\)](#) assert that CBA can theoretically incorporate all costs and benefits to society, including social ones. [Moench et al. \(2007\)](#) claim that while this is theoretically the case, in reality most cost-benefit analyses fail to fully include costs and benefits that are not easily quantifiable. The key benefit of CBA is that because all items are assessed in dollar terms, comparisons between projects and goals are clear ([Heuson et al., 2012](#)). However, there are significant challenges for CBA in terms of valuing intangible assets such as ecosystem services ([Keating and Handmer, 2011b](#)).

[Ackerman and Stanton \(2011, p 6\)](#) state that; “climate economics has often been hampered by its uncritical adoption of a traditional cost-benefit framework, minimising or overlooking the deep theoretical problems posed by uncertainty, intergenerational impacts, and long-term technological change”. [Moench et al. \(2007, p 16\)](#) argue that “[t]he primary value of CBA ... lies in the analytical process itself and the manner in which that can be used to force project proponents to clarify the logic relating to proposed courses of action”.

Disaster economics

The field of disaster research overlaps significantly with climate change adaptation and the threat of increased disasters is driving action on adaptation. This report recognises the importance of the disasters field in informing research on non-linear climate change.

The second half of the 20th century saw the concept of a disaster evolve. University of Chicago geographers, led by Gilbert White, developed a human-ecological view whereby negative impacts could result from interactions between humans and nature (e.g., [Burton et al., 1993](#)). Positive impacts were resources. Over time, ideas about disasters developed to consider the interaction between the natural hazard and the society it impacts ([Alcántara-Ayala, 2002](#)).

The [IPCC \(2012b\)](#) defines a disaster as:

“Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.”

An event becomes a disaster when it overwhelms local capacity, hence local conditions play as great a role in disaster emergence as the natural event. A natural hazard will have significantly different impacts depending on location; for example, a tsunami will create a bigger disaster if it strikes a coastal city, as compared to an uninhabited island. Similarly, the capacity of an affected community or society to cope varies significantly – both internationally and within nations. How different individuals and groups are impacted is mediated by social and political positions; for example, gender roles mean women and men can experience disasters differently.

Much of the work on valuing climate change impacts, and subsequently adaptation, is an application of disaster economics under a changing future. The economics of disaster is often traced to the US Flood Control Act of 1936 ([Moench et al., 2007](#)). This Act formalised the use of benefit-cost analysis (BCA) specifying that flood control works were viable “if the benefits to whomsoever they may accrue are in excess of the estimated costs”.

Since the 1970s, economic analysis has been applied to an increasingly wide range of disaster-related issues at every scale of government. Various guides and reviews have been produced by research groups, government agencies and multi-lateral organisations. These guides and most reviews concentrate on standard cost assessments.

However, the field has grappled with many issues of relevance to adaptation with varying degrees of success. Three long-standing issues in disaster economics of potential relevance to the economics of adaptation are:

- **Intangibles** - identifying and including 'indirect' and 'intangible' impacts – extending loss assessments beyond damage to physical assets for which there are active markets. As monetisation of intangibles could greatly increase the benefits of flood risk reduction strategies, considerable effort has been spent in this area.
- **Maladaptation** - valuing the potential negative effects of strategies intended to reduce losses. For example, decades of research on the 'levee effect' shows how short-run risk reduction strategies that may appear economically optimal can be maladaptive in the long-term, and increase the risk of catastrophe.
- **Transformation** – one view is that relocation is transformative, and disaster economics has long undertaken economic assessments of whether relocations are worthwhile.

Australian studies

A limited number of Australian studies on the economics of impacts and adaptation have been conducted, but this number is expanding. Of the individual costing studies, some have used CBA and others cost-effectiveness. For decisions where adaptation has taken place, most often decisions have been made at the political level on the basis of impact assessments, sometimes with costs attached, then been subject to feasibility or cost-effectiveness assessment.

One author of this study managed a multi-sector study for CSIRO on behalf of the Australian Greenhouse Office in 2003–05 that was never published (*A Sectoral Costing of the Impacts of Climate Change for Australia*), but the study did increase the capacity of the Australian impact and adaptation research community to conduct such assessments, which was eventually realised in the Garnaut Review ([Garnaut, 2008](#)).

The Garnaut Review ([Garnaut, 2008](#)) is the most comprehensive economic modelling project for Australia to date, although it concentrated on mitigation rather than adaptation, costing impacts in a range of sectors for baseline and policy greenhouse gas scenarios. These costing's were estimated from a baseline of zero in 2008, slowly increasing to about 2% of GDP by 2050 (Figure 13). Although these costs were developed to assess the long-term benefits of mitigation and are only partial (omitting some infrastructure costs, non-market costs and insurance for extreme outcomes), they anchor current expectations in Australia as to the costs of climate change.

According to this model, in 2012 the costs of climate change to the Australian economy would currently be about \$3–\$4 billion per annum (Figure 13). However bottom-up costs of single recent events appear be much higher (see Section 3.1.3). It is also difficult to separate the costs of climate change from climate variability. Figure 13 shows that costs to around 2040 are locked in, independent of the effectiveness of global greenhouse gas reductions. This study also reinforces the widely held the perception of gradually increasing costs from a negligible base.

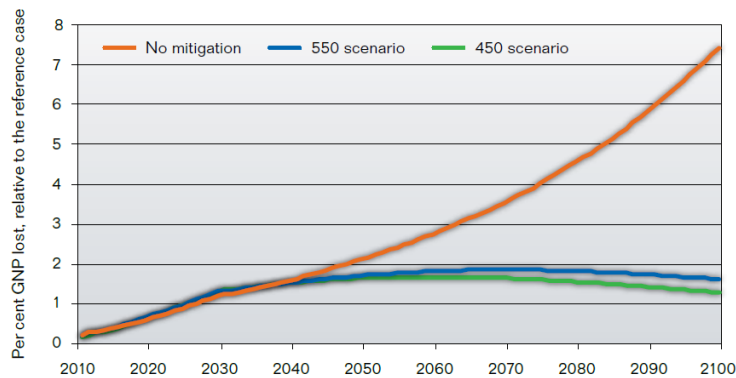


Figure 13. A comparison of the modelled expected market costs for Australia of unmitigated and mitigated climate change up to 2100 ([Garnaut, 2008](#)).

Total environmental value estimates for the Great Barrier Reef have been made in several assessments but the most recent estimate of the present value of the reef calculated over 100 years at a discount rate of 2.65% is \$51.4 billion assessments ([Oxford Economics, 2009](#)). If total bleaching were to occur today, the damage would be estimated at \$37.7 billion at constant net present value. Estimates of direct annual income were \$6 billion from tourism and \$1 billion from commercial and recreational fishing in 2005–06 ([Fenton et al., 2007](#)). Non-commercial values and resilience options for management have been assessed ([Johnson and Marshall, 2007](#)), but specific adaptive strategies for this important system have not been costed.

[Jones and Webb \(2008\)](#) undertook a vulnerability assessment for Victoria that examined the economic geography of sensitivity and vulnerability to climate change in Victoria, contrasting that with adaptive capacity across economic and non-economic sectors. This economic geography has been expanded to the national scale in Section 3.1.8.

State-contingent modelling using CBA has been carried out for irrigation in the Murray Darling Basin under a range of emission scenarios ([Adamson et al., 2007, 2009](#); [Quiggin et al., 2010](#)) that manage the costs of water reductions to the point where the industry can no longer be viable. State contingency sets out a series of options that are exercised according to a simple set of rules based on different irrigation strategies tied to water availability, crop suitability and economic return. [AECOM \(2012\)](#) produced a framework for assessing adaptation based on modifications of cost-benefit and cost-effectiveness assessment to develop a portfolio of adaptation options for sectoral and regionally-based assessments. Specific options could then be evaluated with respect to other options and with the cost of doing nothing. Most of these options (but not all) involved changes to fixed assets rather than changes in operations or behaviour.

3.2.4 Current policy overview

Adaptation policy in Australia is being developed through a Council for Australian Governments' Select Council on Climate Change who are considering a range of work plans and governance arrangements. The Climate Commission provides a key expert advisory role. Although a number of initiatives are presently underway, it is safe to conclude that adaptation policy in Australia is in a state of flux.

Government operates at three levels: federal, state and local. Federal and state governments are included in the constitution and form the Council of Australian Government. Local government is not in the constitution, is largely regulated by state

governments but is a major area of delivery for adaptation. It is also an important link between government and community. Major government policies are summarised in Table 4.

The emphasis on adaptation policy has focussed largely on avoiding duplication in program delivery at different levels of government. It has concentrated less on the role of collaborative policies that are complementary across the three tiers of government. Within government tiers, the concern that policy silos are barriers to adaptation is increasingly being identified.

Brief history of policy development

In 1998, the National Greenhouse Strategy recommended the development of a National Framework for Adaptation to Climate Change ([Australian Greenhouse Office, 1998](#)). This was released as the National Climate Change Adaptation Programme in 2005, which was expanded in 2007, creating the National Adaptation Flagship in CSIRO, a Community Climate and Earth System Simulator under CSIRO, the Bureau of Meteorology and the National Climate Change Adaptation Research Facility, centred at Griffith University ([Department of Climate Change and Energy Efficiency, 2010](#)). NCCARF has developed eight adaptation research plans for sectors and key resources for a comprehensive programme of research. This is funded until mid-2013.

In 2009, the *National Assessment on Climate Change and Coasts* provided a broad analysis of the risks of climate change to coastal settlements ([DCC, 2009](#)). National vulnerability assessments have also been produced for biodiversity, world heritage sites, the national reserve system, and fire regimes. The Local Adaptation Pathways Programs was established in 2008 to assist local councils ([Department of Climate Change and Energy Efficiency, 2010](#)).

In 2007, COAG endorsed a National Climate Change Adaptation Framework as the basis for jurisdictional action on adaptation ([COAG, 2007](#)). The framework established two main areas of action:

- building understanding and adaptive capacity; and
- reducing sectoral and regional vulnerability.

It has also established a Select Climate Change Council (SCCC) ([COAG, 2011b](#)), whose purpose is to:

- support an effective response to climate change policy issues with national implications; and
- provide a forum for the Australian Government to engage with states, territories, local government and New Zealand on program implementation issues.

A Coasts and Climate Change Council was established to advise the Commonwealth government and assist with stakeholder community engagement. The Council has called for a 10-year national agenda for coastal adaptation, aligned “with regional development and population sustainability agendas to reduce the potential for perverse outcomes or maladaptation actions” ([Gurran et al., 2011](#)).

In 2010, a new national adaptation strategy was published (DCC, 2010): *Adapting to Climate Change in Australia: An Australian Government Position Paper*. This listed key adaptation priorities and included the commissioning of a Climate Futures report every five years to evaluate the status of adaptation activity and evaluate the effectiveness of adaptation policy.

The Productivity Commission Barriers to Effective Climate Change Adaptation, Draft Report 2012 ([Productivity Commission, 2012](#)) outlined a number of recommendations in relation to reforms for all levels of governments. Two key recommendations from the report are:

- The Australian Government should focus on National policy responses in areas such as emergency management, research and information provision. Existing agencies still have a role in managing policy responses in this area; and
- The Council for Australian Governments' Select Council on Climate Change, and any successor, should coordinate policy responses in areas where cooperation between levels of government is required.

Currently all states have some level of adaptation policy that is either explicit or implicit, however there is little consistency of process. Many of the state organisations are choosing to take a regional approach to adaptation, and many of the funded activities are focused on a more regional than municipal basis. It is interesting to note that all capital cities in Australia have comprehensive adaptation action plans or strategies. (For specific details relating to policy and regulation see Table 4).

Each Australian state and territory has its own arrangements for disaster planning and management, based very loosely on the nationally agreed *Disaster concepts and principles* ([Emergency Management Australia, 1993](#)), which essentially emphasises the need to work on preparedness and response as well as longer-term prevention and recovery planning. Legislation in each jurisdiction underpins fire and emergency services organisations and their main activities. In many cases, brief statements and operational guides substitute for policy.

Disaster and resilience policy development

In related approaches, especially with respect to the capacity for change and adaptation, boundary-spanning institutional arrangements in government and within the emergency management sector are being developed. The Council of Australian Governments (COAG) has been taking interest in the area, although its reports lack any clear avenue for implementation. Historically, Emergency Management Australia (EMA) took a leading role in promoting reflection and change with the sector nationally through both its training and information arm at Mt Macedon, and through some of the activities of EMA headquarters in Canberra, such as subsidising the salaries of planners in each jurisdiction. This was concerned primarily with moving the sector from an immediate agency response focus to one that included prevention and people.

EMA has now been combined with counter-terrorism and absorbed into the federal Attorney General's Department. The relevant section of the department is promoting the National Strategy for Disaster Resilience ([COAG, 2011a](#)), which helped through a grants program, has been generally well received by state governments and emergency management agencies. This has the potential to promote the flexibility and capacity needed for climate change adaptation – but achieving this would probably require surrender of some power by state authorities to local communities.

Less visible are a range of formal national committees working on advancing emergency risk management (NERAG) and dedicated to a strategic view. These include the RAMMS (risk assessment, measurement and management), and committees dedicated capacity building and community engagement. Other national committees complement these such as the National Flood Risk Advisory Group (NFRAG) which evolved from a semi-formal group of jurisdictions and a few other stakeholders such as insurance, weather forecasting and research. As with the

resilience strategy, these committees have funding for relevant projects on improving the information and knowledge base as well as examining ways of improving the institutional arrangements and processes underpinning an evidenced-based emergency management process.

Separately to this government activity are the national committees of the Australasian Fire and Emergency Services Authorities Council (AFAC). These committees consist of fire and emergency management agencies from across Australia and New Zealand who work on developing evidence-based positions on a variety of subjects, such as community safety, information technology and strategic planning – among many other topics. Relevant agencies – both members and non-members of AFAC – are asked to endorse these positions or approaches. AFAC also led and coordinated nationally agreed changes to bushfire warnings following Black Saturday.

These national committees are explicitly about boundary spanning, learning and change – as such they could provide an institutional mechanism for climate change adaptation. However, the absence of a regular confidential forum for all stakeholders to share reflections and experience may be a barrier to learning.

Private sector and civil society

The private sector and civil society have a patchy understanding of adaptation issues that largely depends on how exposed the sector has been to climate change. Sectors such as primary industry, tourism, actuaries, water providers and insurance have a higher awareness than the manufacturing or small to medium enterprises sector because climate directly affects their core business ([Young and Jones, 2012](#); [ACOSS, 2013](#)). The construction and logistics sectors (particularly infrastructure developers) are endeavouring to gain market advantage by anticipating changing needs for current and new products based on their assessment of projected changes.

Most businesses do not have specific knowledge of climate change and adaptation, but it is implicit in the frameworks and processes within occupational health and safety, quality assurance and change management processes if they are properly observed. Rapid change will impact different sectors in different ways). Knock-on effects from one sector to another are likely.

The community services sector has identified that it is particularly vulnerable to extreme events but currently has limited capacity to recover from such events. In a recent submission to the Senate Inquiry into Recent Trends in Preparedness for Extreme Weather Events, ACOSS stated that *“25% of organisations reported that damage caused by an extreme weather event might lead to its permanent closure”*. They also stated that *“extreme weather events have the potential to seriously disrupt community service organisations’ service delivery and that the consequences of service failure are serious, particularly for vulnerable and disadvantaged sectors of the community.”* ([ACOSS, 2013](#))

Table 4. Current adaptation and associated policies and regulation landscape.

	Policy	Applicable regulation
Federal	National Adaptation Framework National Climate Change Adaptation Action Plan; and National Partnership Agreement on Natural Disaster Resilience National Strategy for Disaster Resilience National Disaster Resilience Framework; Critical Infrastructure Resilience Strategy	National Building Codes National Consumer Law (2011) Clean Energy Futures (2012)
NSW	NSW Sea Level Rise Policy Statement (2010) NSW Coastal Planning Guideline (2010) NSW Coastal Policy (1997) NSW Coastal Design Guidelines (2003) Coastal Risk Management Guide (2010) Flood Risk Management Guide (2010)	Coastal Protection Act 1979 and Coastal Protection Regulation 2011 SEPP 71 Coastal Protection (under Environmental Planning and Assessment Act 1979) Environmental Planning and Assessment Regulation 2000 (amended in early 2011 to require that coastal hazards affected by sea level rise be noted on 'section 149' planning certificates)
Northern Territory	Climate Change Policy (2009) Coastal Management Policy (and) Implementation Strategy 2001	Northern Territory Planning Scheme (addresses flooding and storm surge, as well as 'Primary' and 'Secondary' storm surge areas)
Queensland	Queensland Coastal Plan 2011 Climate Smart Adaptation: 2007-2012 Action Plan Coastal Plan 2011	Sustainable Planning Act 2009 (refers to climate change and sea level rise) State Planning Policy for Coastal Protection (provisions for addressing potential climate change impacts; nb: part of the Queensland Coastal Plan) Coastal Protection and Management Act 1955
South Australia	South Australian Planning Strategy (includes climate change adaptation) Coastline: Coastal erosion, flooding and sea level rise standards and protection policy (1992); source of sea level rise provisions included in all SA Local Development Plans Living Coast Strategy (2004) Draft Climate Change Adaptation Framework (2010) (proposes regional vulnerability assessments, agreements and adaptation plans)	Coast Protection Act 1972 (established Coastal Protection Board) which develops coastal planning policy and is a referral body for coastal development

	Policy	Applicable regulation
Tasmania	Framework for Action on Climate Change (2008) (under review) Climate Change Impact Statements Draft State Coastal Policy 2008	State Coastal Policy Validation Act 2003
Victoria	Victorian Coastal Strategy 2008 Coastal Action Plans and Coastal management Plans (West Coast, Central Coast, and Gippsland Coast) – mechanism for implementing the coastal strategy Climate Change Adaptation Plan (pending 2013)	Coastal Management Act 1995 (Established the Victorian Coastal Council and 3 regional Coastal Boards). Climate Change Act 2010 Terrorism (Community protection Act) 2003 Victorian Government Risk Management Framework 2011 (Department of Treasury and Finance)
Private sector		ISO 31000:2009 Risk Management – Principles and guidelines, AS/NZS 5050:2010 Business continuity - Managing disruption- related risk, (June 2010)

Adapted from [Gurran et al. \(2011\)](#)

3.3 Economic responses to rapid change

3.3.1 Heat stress and transfer

The combination of an ageing population, population growth and step changes in extreme temperatures have the potential to cause very large shifts in the economic costs of heat stress if warming continues unabated.

Extreme heat and mortality models are combined to contrast the economic impacts estimated using standard methods that extrapolate change between time slices and assess continuous gradual change, with the impacts of rapid changes in climate.

Heatwaves pose significant challenges for government because they highlight the problem of risk transfer and risks crossing domains. They are a policy area for front-line health, community health, mental health, criminal justice, built infrastructure, electricity, water, logistics and transport systems, agriculture, food security, heat-sensitive industry and others. Heatwaves impact multiple systems at once, causing compounding or cascading disruptions.

[Keating and Handmer \(2013\)](#) estimated the increase in deaths in Melbourne due to heatwave. They utilised McMichael et al.'s [\(2003\)](#) estimate that in 2003 heatwaves caused approximately 289 deaths annually in Melbourne, predicted increase in population aged 65+ and estimates of projected changes in the annual number of days over 35 degrees, under baseline (exposure increases only) and two climate change scenarios (adapted from Climate Change in Australia 2012). Valuations based on the value of a statistical life of \$3.95 million using figures from [Department of Finance and Deregulation \(2008\)](#).

With no adaptive change, by 2050 increases in heatwaves due to climate change will have caused an additional 6214 deaths (or 402 deaths annually by 2050) over and above the no climate change scenario (Table 5). These figures translate to an additional \$6.5 billion (or \$225 million per annum by 2050) loss over and above the no climate change scenario. (CSIRO3.5 climate model, 5% discount rate, 2011 \$AUD).

Table 5. Total number of deaths and valuation by 2020 and 2050 due to heatwaves under baseline and climate change scenarios.

	2020 Exposure only	2020 Miroc3.2	2020 Csiro3.5	2050 Exposure only	2050 Miroc3.2	2050 Csiro3.5
Number of deaths	4287	4436	4522	23222	27161	29436
Valuation, \$millions AUD2011, 5% disc. rate	\$13,162.9	\$13,568.1	\$13,801.7	\$35,057.6	\$39,197.6	\$41,608.9

The estimate of less than 300 deaths per annum in 2003 was overwhelmed during the 2009 heatwave in Victoria when 374 people are assumed to have died during that single event. This shows the current impact model to be conservative.

Potential heat deaths were also tested under rapid changes in extremes.

A single model run of summer temperature from a grid square over Melbourne from the CSIRO Mark3.5 A1B model run from the CMIP3 archive is used to show the effect of

rapid warming on heat deaths. Four different estimates were produced: climate only (1871–2099); climate plus total population growth for Melbourne (1971–2099); climate plus 65 and older population; and smoothed climate plus 65 and older population (2010–2090). Population growth was as for [Keating and Handmer \(2013\)](#) to 2050, then extrapolated to 2099 at a slightly slower rate.

Figure 14a shows similar death rates to those simulated by [Keating and Handmer \(2013\)](#), which would be expected using similar models and data. Shifts in the order of 100 people per year under constant population and 200 per year under a mid-range projection of population growth for Melbourne occur using this data directly (Figure 14b). Adding population growth to climate change roughly doubles the simulated death rate. Higher rates of population growth aged 65 or older accelerate those at risk of heat deaths (as shown in Figure 14c), where the rate is roughly three times that of climate alone and potentially five times by 2099. In context, the current cohort of Melbourne's 65+ population is 18%, which is projected to increase to 30% by 2030, and under this model would be 48% in 2099. We do not estimate whether a roughly 4°C warmer planet 2099 could support such a population in Melbourne.

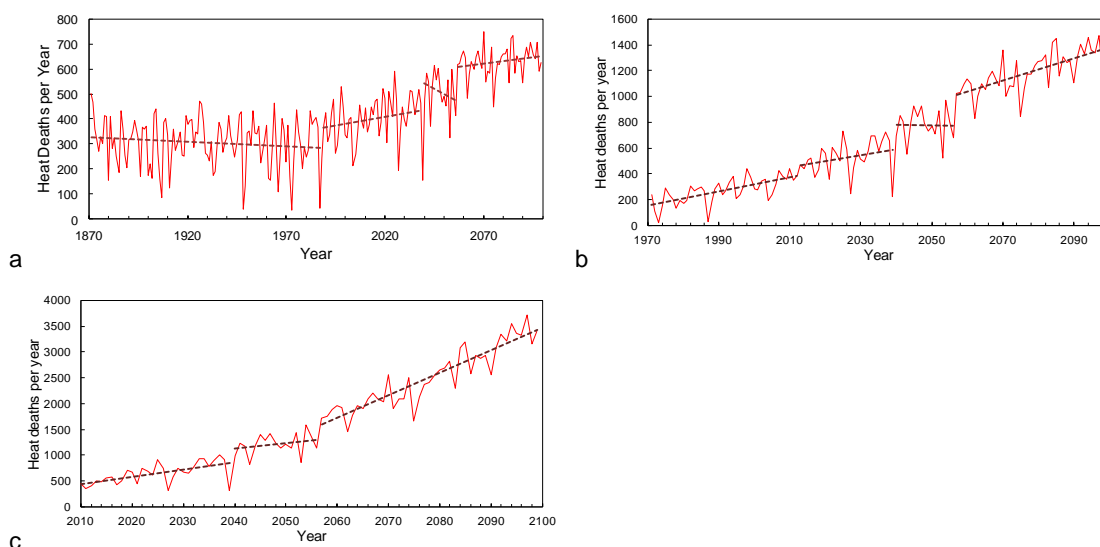


Figure 14a) Simulated heat deaths for Melbourne using a single climate model simulation showing statistically significant step changes in death rates with constant 2011 population; b) heat deaths for Melbourne with population increasing according to recent estimates from the Victorian Department of Human Services and the ABS; and c) as for b) with population increase in 65 and older group.

Applying the same costing's as [Keating and Handmer \(2013\)](#) to estimate the economic impacts shown in Figure 14 shows some interesting results. Firstly, the model shows slightly greater baseline mortality due to its construction based on annual data rather than a baseline mean period. Total deaths (2010–20 due to population exposure only) are 5,186 compared to 4,287 from Table 5, and this is simply due to a warmer starting temperature. Deaths in 2020 are 5,597, an increase of 400. Total deaths by 2050 under climate change plus exposure are 32,305 – about 2,000 fewer than in Table 5.

Table 6. Total number of deaths and valuation by 2020, 2050 and 2099 due to heatwaves under baseline and climate scenarios representing gradual and variable change.

	2020 Exposure only	2020 Gradual climate	2020 Variable climate	2050 Exposure only	2050 Gradual climate	2050 Variable climate
Number of deaths	5186	5184	5597	28090	31614	32305
Valuation, \$millions AUD2011, 5% disc. rate		\$15,929	\$17,115		\$45,867	\$47,046
	2099 Exposure only	2099 Gradual climate	2099 Variable climate			
Number of deaths	102436	146508	147542			
Valuation, \$millions AUD2011, 5% disc. rate		\$65,166	\$66,842			

Of more interest are the differences between the variable and gradual climate change, and of the effect of discount rates on those differences. Figure 15 shows the annual VSL for three discount rates; 0, 2.5% and 5% along with the accrued difference between the gradual and variable climate change scenarios. Although this example is using perfect foresight, if the green line is above zero, then addressing the risk of non-linear change by treating gradual change as conservative is the better strategy. If the line is below zero, then addressing gradual change is the better strategy.

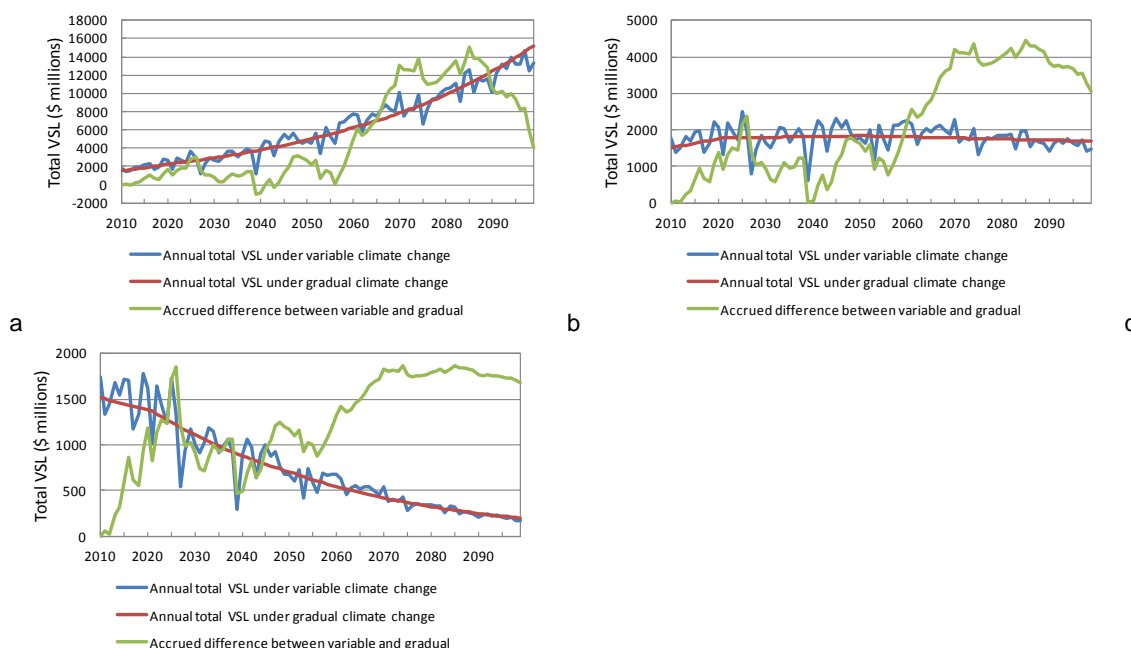


Figure 15. Annual total value of a statistical life (VSL) for Melbourne, based on rate of change of the population 65 and over and change in maximum temperature from the CSIRO Mk3.5 A1B simulation, represented as individual year averages for Oct–Mar and the accrued differences between the two in \$million AUD2011 for a) zero discount rate, b) 2.5% discount rate, and c) 5% discount rate.

Clearly, addressing the adaptation deficit as a non-linear problem is the better strategy because the difference between the two potential strategies stays above zero for most

of the century under all discount rates. There is a benefit in acting to reduce losses to 2020 in all cases, rather than taking a gradualist approach.

The aim of this example is to illustrate gradual versus nonlinear change using a risk that is already affecting most Australians. Most of Australia's major population centres are experiencing greenhouse-enhanced heatwaves. However, there are caveats – for example:

- Death rates represent current vulnerability and age structure patterns. Improvements in housing and heat stress management would reduce exposure to heatwaves but larger urban heat islands, if unmanaged, would increase it.
- The heat stress models used underestimate the heat death relationship at higher daytime temperatures as indicated by the number of anomalous deaths estimated in the 2009 heatwave compared to the baseline estimate.
- Outputs for the Melbourne region and SE Australia from over 20 climate models show a similar pattern of step changes in maximum temperature in all models. Similar changes are considered highly likely under warming conditions. Whether they are limited by reductions in greenhouse gas emissions might be assumed, but this has yet to be shown.

3.3.2 Fire risk

Based on recent rapid increases in the forest fire danger index (FFDI) in south-east Australia and step changes in key climate variables that influence FFDI, fire risk has the potential to change rapidly under climate change putting people, forest resources and ecosystems at risk.

As for the heat stress case study, we compare standard time slice assessments for 2020 and 2050 and smooth projections to 2100, with those using direct model output estimating annual variability in fire risk.

[Keating and Handmer \(2013\)](#) estimate current bushfire damage costs associated with the Victorian agricultural and timber industries developed from Stephenson's [\(2010\)](#) estimates of the cost of five major bushfires from 1983–2009, complemented by data from three further fires. Two scenarios for future fire weather are taken from Lucas et al.'s [\(2007\)](#) models of predicted increases in days when FFDI exceeds 50.

They estimate the current total cost to the Victorian economy due to bushfire damage to the agricultural industry (including business disruption costs) to be \$92 million per annum, and then extrapolate future losses. The baseline scenario accounts for increases in exposure only (Table 7).

With no adaptive change, by 2050 increases in bushfire damage to the agricultural industry due to climate change would cost the Victorian economy an additional \$1.4 billion (or \$47.9 million per annum by 2050) over and above the no climate change scenario. (Table 7; High Mk3 climate change scenario, 5% discount rate, 2011AUD).

Table 7. Total damage costs to Vic agricultural industry under baseline and climate change scenarios by 2020 and 2050, \$millions \$AUD 2011

Scenario for change in number of days where FFDI>50	2020 No climate change	2020 low mk2 – 11%	2020 high mk3 – 40%	2050 No climate change	2050 low mk2 – 19%	2050 high mk3 – 138%
Present Value (discount rate = 5%)	\$922.2	\$972.0	\$1,090.8	\$2,457.3	\$2,801.6	\$3,874.5

The current total cost to the Victorian economy due to bushfire damage to the timber industry (including business disruption costs) is estimated to be \$185 million per annum. The baseline scenario accounts for increases in exposure only (Table 8).

With no adaptive change, by 2050 increases in bushfire damage to the timber industry due to climate change will have cost the Victorian economy an additional \$2.85 billion (or \$96.2 million per annum by 2050) over and above the no climate change scenario. (High Mk3 climate change scenario, 5% discount rate, 2011AUD).

Table 8. Total bushfire damage costs to Vic timber industry under baseline and climate scenarios by 2020 and 2050, \$millions AUD2011.

Scenario for change in number of days where FFDI>50	2020 No climate change	2020 low mk2 – 11%	2020 high mk3 – 40%	2050 No climate change	2050 low mk2 – 19%	2050 high mk3 – 138%
Present Value (discount rate = 5%)	\$1,850.9	\$1,950.8	\$2,189.4	\$4,931.9	\$5,622.9	\$7,776.3

[Keating and Handmer \(2013\)](#) also estimate the cost of bushfires to the intangible assets of ecosystem services. They find that by 2050, increases in bushfire damage in south-eastern Australian ecosystems due to climate change will have cost an additional \$1.5 billion, over and above the costs if no climate change took place.

The estimates by [Keating and Handmer \(2013\)](#) are considered to be too low because current cost estimates are limited by data availability. These estimates are based on a simple, linear extrapolation that assumes a one-to-one relationship between damage and increases in extreme heat days, which is methodologically convenient but likely to under-estimate losses.

Non-linear changes in FFDI estimated from changes in annual temperature and rainfall anomalies were estimated from data taken from the Laverton station and calculations of FFDI from [Lucas \(2009\)](#) adjusted to remove inhomogeneities in wind data. They were applied to the same economic data as used by [Keating and Handmer \(2013\)](#) and applied to model climate output using a transfer function for days above high fire danger. Figure 16 shows statistically significant step changes in the early 2000s and mid-2050s, with intervening periods showing a mild trend. The changes in the early 2000s are similar in scale to recent changes in FFDI for Victoria (Figure 17).

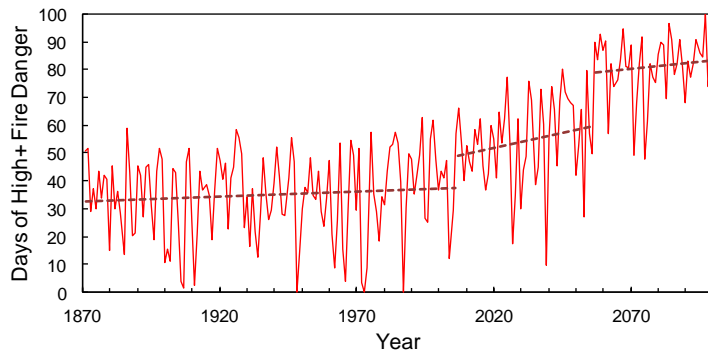


Figure 16. Estimated changes in days of high to catastrophic fire danger based single model run of annual maximum temperature and total rainfall from a grid square over Melbourne from the CSIRO Mark3.5 A1B model, based on Laverton data.

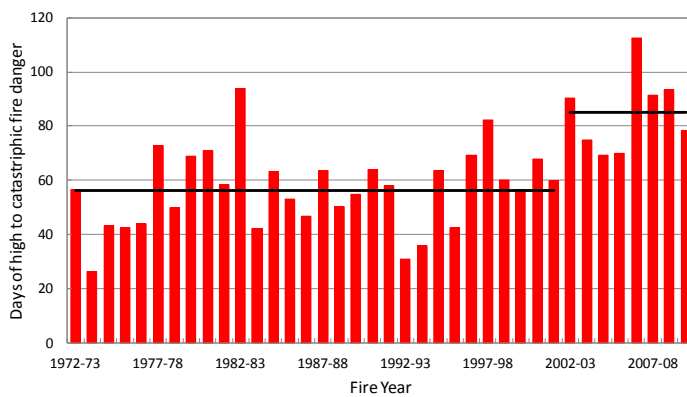


Figure 17. Average number of days of high to catastrophic fire danger days per year from nine Victorian stations, adjusted for inhomogeneities in wind speed. Original data from [Lucas \(2009\)](#).

Resulting total losses are similar for both gradual and variable scenarios (Table 9), and are slightly higher than those of [Keating and Handmer \(2013\)](#) for 2020 and slightly lower by 2050. This is because from 2010–2050, there is little trend in the input data, followed by a step change in 2056, then another period of little trend to 2100 (Figure 18a).

Figure 18b–d shows the potential losses can increase significantly in dollar terms in future, with Figure 18c showing close to the net costs of climate change has the discount rate is almost equal to the underlying increases in exposure. The model shows that an early investment in adaptation would pay off compared to a wait and see strategy, but lack of change mid-century sees wait and see take over as the best strategy, except that the step change in 2057 causes damages to escalate rapidly even under discounted losses.

Table 9. Total losses to agriculture and timber production by 2020, 2050 and 2099 due to changing fire risk under baseline and climate scenarios representing gradual and variable change.

	2020 Gradual climate	2020 Variable climate	2050 Gradual climate	2050 Variable climate	2099 Gradual climate	2099 Variable climate
Agriculture loss, \$millions AUD2011, no disc. Rate	\$1,498	\$1,467	\$10,697	\$10,521	\$70,623	\$71,150
Timber loss, \$millions AUD2011, no disc. Rate	\$3,006	\$3,304	\$21,470	\$21,115	\$141,742	\$142,800
Total loss, \$millions AUD2011, 5% disc. Rate	\$3,501	\$3,875	\$11,145	\$11,210	\$18,175	\$18,415

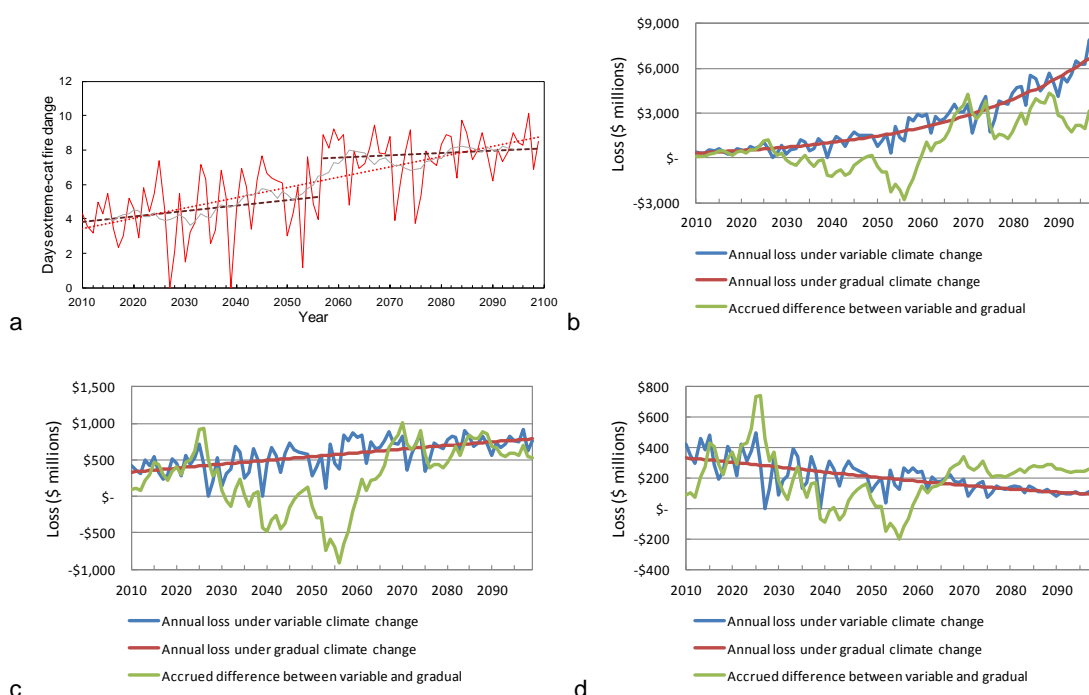


Figure 18. Average number of days of extreme–catastrophic fire danger for Victoria derived from maximum temperature and rainfall from the CSIRO Mk3.5 A1B simulation. a) Data represented for fire years, showing output (red line), trends (brown dashed line), separated by a step change (2057), along with a simple trend (dotted red line). Annual loss and accrued difference between the raw data and trend line in \$million AUD2011 for b) zero discount rate, b) 2.5% discount rate, and d) 5% discount rate.

Many of the caveats for this case study carry through from the previous one. One reason why the fire risk case study shows less non-linear behaviour than heat alone is that rainfall in model output shows fewer step changes than temperature. Statistically significant step changes occur in only about half of twenty models investigated for south-east Australia, whereas temperature showed multiple step changes in all models. This may be due to climate models not representing hydrological sensitivity to climate change well enough, rainfall being less prone to such changes or a combination of both.

3.3.3 Assessing risks and risk propagation

Management of domain crossing – also conceptualised as boundary crossing – requires clear ownership and responsibility for the risk concerned and, in many cases, for the impacts resulting from an event connected with the risk. A focus on the impacts alone will likely result in the risk or threat being ignored or treated as someone else's responsibility. It also requires coordination across government and across society, as the risk crosses into many sectors, jurisdictions and temporal and spatial scales. The risk needs to be owned, and considered as a whole so as not to inadvertently facilitate maladaptation – adverse impacts as a result of the risk management process in a sector or domain that should have been, but was not involved.

Climate risks are defined here according to a modification of Rosa (2003) as a *climate-related situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain.*

Values at risk can be considered as any monetary or non-monetary value attached to the function or existence of an entity or process. Values can be determined by a wide range of economic or survey methods and range from monetary, fungible values (readily substitutable) through to a stated value expressed in qualitative terms.

Often there is a tension between who values a risk and who has responsibility for managing that risk, especially for intangibles attached to social and environmental values. Often risk ownership is shared – institutional analysis can be used to determine shared ownership and thus the context and potential for adaptation. In governance terms, one institution may set the formal rules (e.g., state or federal government), another may manage the risk in its current status (e.g., local government or industry) and yet another may be responsible for planning future adaptations (e.g., another state department, a regulator or appointed working party).

A key concern of this project is the propagation of risks across domains. An identifiable geographic, sectoral or institutional scale is referred to as a domain. A domain is considered as an area of institutional influence that is exercised through governance. That sphere of influence is delineated by rules, control, knowledge and agency. Regions and levels of government form an important link between geographic and institutional domains (Figure 19).

Climate-related risks, mainly extremes, will occur singly or combine in generally unpredictable ways, propagating across domains if they are large enough, if several are in quick succession or stress accumulates over time. The crossing point between domains can be considered as thresholds or boundary crossings. These thresholds mark the point where an impact crosses into another domain or where the responsibility for responding to or managing a risk crosses domains. These thresholds are equivalent to those in Section 3.1.3, where some form of coping capacity is exceeded, inviting a management response. If an impact crosses domains and there is no corresponding institutional responsibility for responding to the resulting risk or to future risks, then those risks are un-owned.

Areas of risks crossing domains based on recent climate-related events include the high-income flood levy to pay for the Commonwealth support for the Queensland 2010–11 floods; enquiries in Queensland, Victoria and the ACT to investigate fires and floods; land buybacks after the Victorian and Queensland floods and Victorian fires; Commonwealth support for rebuilding after tropical cyclones in Queensland; responses to the drought of the century via state intervention in desalination, and so on.

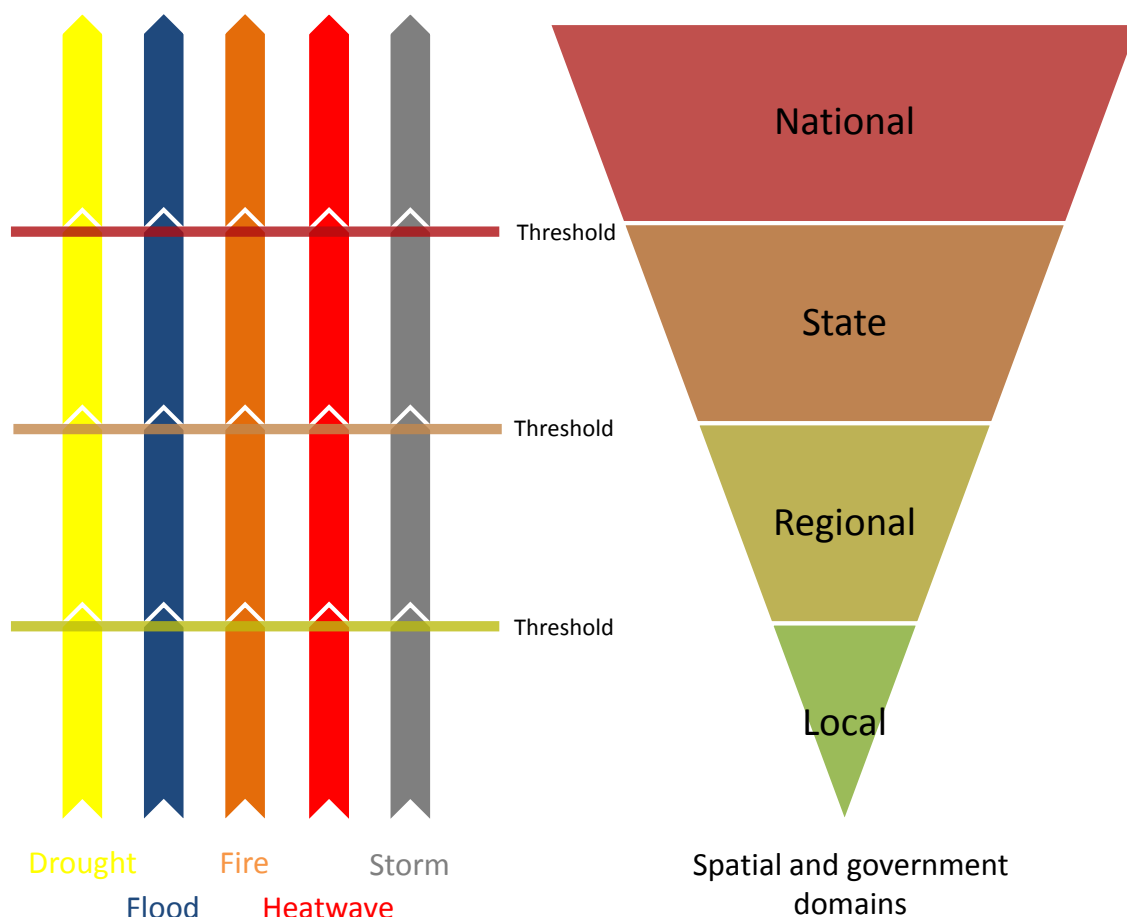


Figure 19. Schematic representation of spatial and government domains with some extreme events likely to cross domains either singly or in succession.

Domain-crossing brings up the following concerns:

1. Who values the risk and who is responsible for it before it in its normal state?"

And if it propagates from one domain to another:

2. How does that risk manifest in the new domain, who accepts the responsibility in its new domain and who may be responsible for adapting?"; and
3. "What is the threshold/limit that marks the crossing of domains?"

Managing risk domain crossing in Australia

Cross-sector and cross-jurisdictional collaboration are needed to reduce the negative impacts of domain crossing. We consider the readily available national mechanisms for risk identification and management, and the main impediments to this occurring.

National mechanisms and institutional framework:

National approaches to managing climate (and other) risks such as NERAG (National Emergency Risk Assessment Guidelines ([National Emergency Management Committee, 2010](#))) and its four national implementing committees, NFRAG (National Flood Risk Advisory Group), and AFAC (the peak association of Australian fire and emergency management agencies) and its national committees, the National Police and Emergency Management Ministers Council and occasional action by COAG, the national recovery and hardship grants system, as well as the national Emergency

Manual series by EMA (now Attorney Generals) appear to provide a national institutional framework of long standing for the identification and management of climate related hazards and risks in Australia. The national research bodies of NCCARF and the Bushfire CRC (and to a lesser extent VCCCAR and its NSW equivalent), have provided research support.

There is a national standard (based on the Australian standard AS/NZS4360, now the international risk management standard ISO31000 ([ISO, 2009](#))), for the management of emergencies, which prescribes a process and, to some extent, suggests a national approach if all relevant agencies adopt them. This is set out in the NERAG guidelines mentioned above. There is not a standard for Climate Change Adaptation at present, but the mechanism for its development exists.

The most recent addition to a national approach for the management of emergencies and climate risks was in 2011 with the announcement of the National Strategy for Disaster Resilience ([COAG, 2011a](#)). This is a document setting out a strategy where the responsibility for the management of natural hazards would be revisited and all parts of Australian society, including communities and individuals, would be expected to play their role. There is more on the strategy's main themes below.

The main gap in terms of clear processes is with exposure to hazards. Exposure, in terms of people and economic activities, appears to be expanding steadily, despite calls from [COAG \(2004\)](#) and post-disaster enquiries ([Teague et al., 2010](#)), for example, the Victorian Bushfires Royal Commission 2011. It is driven by other factors considered in the planning process and natural hazards are rarely seen as a significant issue. Given that national projections are for a doubling of Australia's population over the next 50 years, exposure will become much more of an issue. Increasing exposure is not simply an Australian issue – globally it is the main driver of increasing disaster losses ([IPCC, 2012b](#)).

Another significant gap in national cross-domain institutional capacity appears to be in learning from disasters and, just as importantly, learning from near-misses. Australia holds many post-impact enquiries which make many, often high-profile recommendations. It is unclear to what extent these are implemented so as to improve practice and outcomes both for the risk and for response in an emergency. This issue is of particular concern with climate change adaptation, as learning and change to adapt to new circumstances is seen as fundamental. Without learning, adaptation will be accidental.

National processes, committees and guidelines exist and there is a strengthening commitment to national uniformity suggesting that the future could bring greater collaboration across jurisdictions and sectors. However, ownership of risk in terms of action, as opposed to policy and guidelines, is not as well catered for. It is very easy to blame constitutional arrangements, but compared with the EU and most federations, Australia's system of government is relatively simple. Nevertheless there is partial risk ownership through ownership of the risk identification and assessment processes, but cross-domain arrangements fall away when it comes to implementation on the ground.

The National Strategy for Disaster Resilience

The National Strategy for Disaster Resilience (NSDR) was released in 2011, just after the severe floods in Queensland ([COAG, 2011a](#)). Its introduction quotes the Prime Minister's National Security Statement of 2008; "Climate change represents the most fundamental national security change for the long-term future." It is based around a number of actions emphasising collaboration, capability development, knowledge and

responsibility. It is important to note that at present “resilience” is not defined by the strategy and no quantitative criteria for measurement are proposed.

Senior officials have been tasked, and government committees have been established, in many Australian jurisdictions to promote the strategy and its implementation. It has generated intense interest and debate about the role of government and the appropriateness of a “resilience” approach.

The strategy (as set out in its published form) appears to fit well with the concept of domain crossing by risks, as it contains some of the key elements needed to manage cross-domain issues. It explicitly addresses the questions of risk ownership and responsibility for that risk in a whole of society context. It does not answer these questions or provide solutions, but it highlights their importance and suggests an approach based on building a resilient society.

The strategy argues for much more than a whole of government approach – it advocates a whole of national approach integrated across government, commerce and civil society. Part of this would involve interoperability, resource-sharing and expertise across the country. At this stage there are no details on implementation, although a high degree of collaboration and sharing of knowledge, expertise and resources should reduce the issues associated with domain boundaries.

Domain crossing by risks

Larger complex risks and events are more likely to cross multiple domains because they naturally spread across jurisdictions, involve multiple parties and sectors, and are loosely bounded in space and time (see also “complex unbounded problems” in [Handmer and Dovers \(2013\)](#)). More frequent extreme climate events could result in more frequent domain crossing, but climate extremes alone are only part of the picture. Increases in exposure are probably the major factors behind increased disaster losses ([IPCC, 2012b](#)), and the apparent increased complexity of disasters. Increased exposure includes:

- increases in population;
- changes in population location to higher hazard areas such as bushfire-prone forests;
- greater use of bush areas for recreation and lifestyle changes; and
- economic activities, in particular infrastructure and recreational, in hazard-prone areas.

Changes in livelihoods and the complexity and interdependence of our systems and society, the ready mobilisation of national and international assistance, expanding use of the military in emergencies, aid and compensation from national and international sources, and what can be seen as a tendency to allocate blame and responsibility to identified individuals rather than to sectors or to social priorities, all contribute to complexity and multiple domains in disaster.

Domain crossing is not simply a large complex event. A well-defined event, such as an intense hail storm or building fire, can have far-reaching, even global, repercussions through, for example, the subsequent enquiry, decisions made by insurers, or litigation. These can involve sectors and jurisdictions that have no direct impact from, or role in, the event or even in the management of the risk. They can make the risk appear unbounded in space or time. A specific example is provided by food security. In Australia, most food is distributed through a few nodes or transshipment points from where it is sent to local distributors. The national food logistics chain is an outstanding

example of 'just in time' management, and at any one time contains a few days food supply ([Keating, 2013](#)). Severe disruption of a node by a bushfire (an emergency management incident), could have a major impact on food supply logistics (commercial food transport and logistics) in a capital city (people, food dependant and related commerce, and state and local government) with flow-on effects to more isolated regional locations. If a significant food shortage developed, rationing would be required and critical facilities such as hospitals and schools would need priority. The event would quickly become a crisis of confidence in risk governance.

3.3.4 Adaptation clusters

Impacts have a range of values with different economic and ethical characteristics. Impacts on values can range from immediate loss to long-term erosion of values; their recovery time will also vary. The economic effects of impacts range from being direct (tangible) to indirect (intangible), they range from being substitutable to irreplaceable and from being a permanent loss to being recoverable through various means.

Based on these broad effects, we have divided impacts into five types of adaptation clusters: goods (production systems); services (operational systems); capital assets; human and natural assets; and infrastructure. This so that these different values can be explored using a variety of valuation methods, rather than trying to monetise them all into a single, fungible value system where any value can be exchanged with any other.

The five clusters are summarised below:

- **Goods** – production system threats and opportunities range from being climate centric (e.g., food and fibre, some tourism, water supply, power supply) to climate influenced (e.g., mining, tourism, construction, power generation and distribution), in order of decreasing sensitivity. Loss of production comes at a direct cost to the economy.
- **Services** – includes operations not included in production systems such as transport and logistics, communication and general commercial services – the largest proportion of the Australian economy. Interrupted services and supply chains will come at a direct cost to the economy. Services range from being climate sensitive (tourism) to being relatively insensitive to all but disasters.
- **Capital assets and infrastructure** – standing assets affected by climate and weather events, climate-induced deterioration and sea level rise processes may need protection, retrofitting or retirement. New assets and infrastructure may need to be built to cope with a changed climate. The net economic impacts of rebuilding existing assets and building new fit for purpose assets are opportunity and transaction costs that will be returned as avoided damages at a later date.
- **Social assets and infrastructure** – changes to society and human welfare that include health, education, social connectedness, finance and savings and the arts and humanities. These largely constitute adaptive capacity, but also may have inherent value (e.g., human health, knowledge and art). Links between this cluster and the economy may not be direct and are often difficult to measure, but are notable if they degrade or become absent.
- **Natural assets and infrastructure** – changes to the environment affecting ecosystem services in the form of green infrastructure, direct goods and services including cultural services and amenity value. The direct cost to the economy through the loss of natural assets is extremely difficult to calculate. At the global

scale, ecosystem collapse can lead to catastrophic economic impacts. At the national scale, long-term economic and social returns could be substantially reduced by a failure to invest in maintenance and ecological resilience.

A sensitivity analysis assigned each of 168 economic activities to a particular cluster, as classified by the Australian Bureau of Statistics. Each activity was then classified according to high, medium and low sensitivity to climate change after [Jones and Webb \(2008\)](#).

Table 10 shows fifteen Australian economic sectors divided into the five clusters. Asterisks mark particular sectors as having important attributes of adaptive capacity. Opportunities for adaptation are also briefly described.

We summed gross income from the financial year 2005–06 to get a rough estimate of the contribution of each cluster to the economy. Figure 20a shows a national summary of adaptation clusters as a proportion of gross national income. This is approximate because at the activity level, some activities combine adaptation clusters. For example, some tourism and agricultural activities will draw income from environmental assets and infrastructure. There is also a two-way relationship between many services and social assets and infrastructure.

These clusters show differing weights in the monetary economy (Figure 20). These relative differences, rather than the exact numbers themselves, are important for addressing the different values at risk from climate change. Expenditure patterns will show a somewhat different picture. For example, governments and private landholders both spend money on social and natural assets and infrastructure, which would raise the proportion of those clusters above 12.6% and 0.1% respectively. They would, however, remain comparatively small compared to the other three, whether assessed in income or expenditure terms.

To create a more complete picture, national accounts for environmental and social assets need to be integrated with financial accounting, but in such a way that combines income and assets without double counting.

Figure 20b shows the sensitivity of total gross annual income to climate impacts at the national level. Because the sensitivity of each activity was rated at the national rather than regional scale, some activities rated at low or negligible levels nationally may be highly-exposed in certain regions (e.g., infrastructure in fire prone areas or on the coast). A regional breakdown of exposure and sensitivity according to statistical divisions or local government level would show greater levels of sensitivity to rapidly changing risks than can be achieved using a national assessment.

Having a more detailed picture of values at risk as a function of hazards, sensitivity and exposure is necessary for undertaking a comprehensive economic assessment of rapid change scenarios.

Table 10. Australian sectors showing adaptation situation with main threats and opportunities, couched in general economic terms.

Sector	Cluster type	Main threats	Potential opportunities
Agriculture, Forestry and Fishing	Goods	Production losses, asset damage	Goods gains, lifestyle diversification, research to value more fully the worth of these assets
Mining	Goods	Production losses, asset damages, supply chain disruption	Raw materials for new tech, development of resilient strategies, policies and infrastructure.
Manufacturing	Goods	Supply chain	Adaptation products
Electricity, Gas and Water Supply	Goods/Services/Capital assets	Raw material supply and operations, service delivery	Transformation, inclusion of redundancies.
Construction	Goods/Capital assets	Delays, supply chain, asset write-offs, diminished capital	Adaptation of assets – Development of new materials and processes
Wholesale Trade	Services	Supply chains, raw materials	Flexible supply, good forecasts
Retail Trade	Services	Supply chains, raw materials	Flexible supply, strategic alternatives to fulfilling consumer needs,
Accommodation, Cafes and Restaurants	Services	Disruption to food and energy supply, damage to assets, diminished capital, increase in demand	Strategic sourcing of food, alternative energy supplies,
Transport and Storage	Services*	Infrastructure damage, damage to assets,	Flexible arrangements for disaster and recovery. The development of new technologies and material
Communication Services	Services*	Infrastructure damage, disruption of service delivery	Flexible arrangements for disaster and recovery, new tech for adaptation. Backup systems
Finance and Insurance	Human Assets*	Large insurance losses, finance shortages	Services for adaptation
Property and Business Services	Capital Assets*	Economic dislocation at regional scale	New ownership models, part in setting standards
Government Administration and Defence	Services/Human Assets*	Lack of capacity to be able to respond effectively. Poor communication, poor coordination, poor information	Policy, emergency and disaster, funding for adaptation, support for building adaptive capacity
Education	Services/Human Assets*	Severe weather events and disasters affecting operations. Poor information, lack of appropriate policies	Policy development and awareness building and training in relation to rapid changes.
Health and Community Services	Services/Human Assets*	Lack of capacity to deliver services to vulnerable communities. Poor information	Capacity building for sector, the development of appropriate information and strategies
Cultural and Recreational Services	Services/Natural Assets *	Loss of services and basic system functions. Community disconnection	Models for community engagement, making the invisible economies visible. Capitalising on the current cultural and social systems

* Sectors carrying a significant degree of adaptive capacity

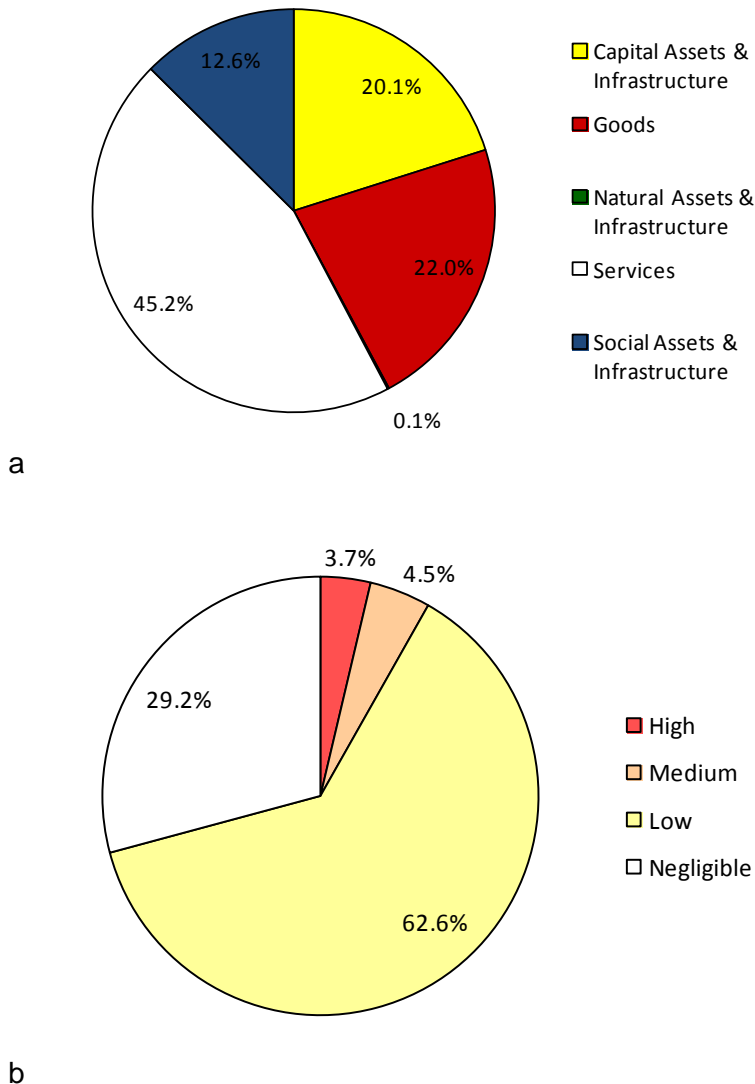


Figure 20. National summary of adaptation clusters according to a) gross income 2005–06, and b) sensitivity as a proportion of income.

3.3.5 Understanding the problem at the national scale

In this project, we have summarised localised case studies in order to illustrate the issue of rapid climate change. The elements of the problem that need to be understood at the national scale include:

- The regions likely to be most affected by rapidly changing extremes. Although this can be judged qualitatively, some quantitative studies using climate model data would be beneficial;
- The values exposed in those regions measured according to adaptation cluster and exposure to rapidly changing hazards. This will comprise an economic geography of current and potential future risks; and
- The resulting institutional structures most likely to be affected by rapidly changing risks at the regional to national scale.

The first two points combined can be used to develop an economic geography of climate risk, building on the preliminary version in the previous section. A more detailed version could be developed using regional economic data and past and future hazards. As yet, Australia does not have a national hazard database, although Geoscience Australia is in the process of building one. Risk Frontiers at Macquarie University has a database of historical insurance events under intellectual property protection. The last published national hazard map was by [Blong \(2005\)](#), who integrated six hazards: bushfire; earthquake; flood; landslide; thunderstorm; and tropical cyclone into a map of existing hazard and hazard potential (Figure 21).

The economic geography of exposure to rapidly changing hazards in Australia remains unknown, although a casual glance at the economics of the adaptation clusters, which will follow population density (overlain on Figure 21) would suggest that high values and hazards coincide on the east coast of Australia, the south-east and the south-west. Asset data-bases are held by private industry, Geoscience Australia and a range of state agencies. Spatial tools that can combine hazards with assets, such as that being developed by the Victorian Managed Insurance Authority, will be of immense value in projecting future risk.

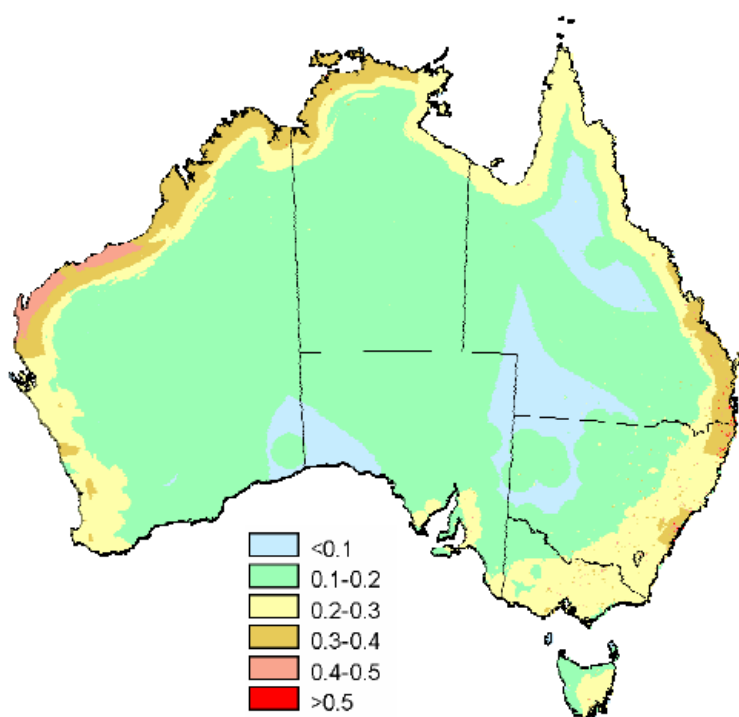


Figure 21. Integrated natural hazards map of Australia developed from past hazard vulnerability (30%) and hazard potential (70%) ([Blong, 2005](#)).

The joint filters of gradualism and predictive power also limit the questions being asked of climate impact and risk assessments. The past few years have seen successive droughts, bushfires and heatwaves interspersed with flood events and tropical storms that are increasing the cost burden both publically and privately. Their cumulative impact, or the potential for such events to escalate and cross ill-defined critical thresholds, is unknown. Sufficient knowledge exists to create credible scenarios involving a rapid change and succession of extreme events, and to test various adaptation management strategies.

Our earlier analysis suggests that large-scale propagation of risks across the Australian economy and policy landscape due to rapid changes in climate extremes is likely to occur in the future. Such changes include:

1. likely step changes in temperature;
2. potential step changes in rainfall; and
3. combinations of severe weather events coming in rapid succession, some related to climate regimes such as ENSO and others unrelated.

The interval between extreme weather events will become smaller, even if some events (such as tropical cyclones) retain their current frequency but increase in severity. The recovery time between such events would then reduce, perhaps rapidly. Potential damages will also accelerate due to increases in exposure, especially in coastal and fire prone peri-urban areas.

Two pieces of information are vital to understanding the potential future risk burden. The first is the economic geography of climate-related risks across Australia and the second is a comprehensive accounting of the exposure to change taking in monetary, social and environmental concerns. Superimposing rapid changes on this framework and assessing total costs may provide an approximate order of magnitude estimate of future risks.

3.3.6 Key factors for assessing and valuing rapid change

This section summarises a number of methods and tools that contribute to economic assessments. The application of these economic methods and tools is summarised in Section 3.2.3.

Uncertainty

Uncertainty is usually associated with predicting various outcomes of a cause and effect process, in this case the 'climate change problem', and with assessing various options to manage that problem. These can be considered as predictive and diagnostic uncertainties associated with exploratory (what happens when ...) and normative (what happens if ...) scenarios ([Carter et al., 2007](#)). Uncertainties that are considered less frequently include framing uncertainties – that shape an action situation and frame its boundaries, and conceptual uncertainties – that assess the existing models for understanding the particular problem-solution-implementation context ([Mastrandrea et al., 2010](#)) and whether they are qualitative or quantitative.

Uncertainties that relate to understanding the problem include:

- Uncertainty about the extent of future greenhouse gas emissions, which depends on future scenarios of global mitigation agreements, global population growth and technological change ([IPCC, 2007a](#)).
- Uncertainty about the effect of emissions on mean climate variables. Climate models predict some of these variables better than others ([Agrawala et al., 2012](#); [IPCC, 2012b](#)).
- Uncertainty about changing extremes, which is larger than for mean changes ([CSIRO and BoM, 2007](#)) but is arguably more important for adaptation decision-making ([Jotzo, 2010](#)).
- Local level projections, which are more uncertain than global projections ([CSIRO and BoM, 2007](#)), although most adaptation decisions are experienced at the local scale ([Agrawala et al., 2012](#)).

- Uncertainty about future socio-demographic conditions and future vulnerabilities ([Handmer et al., 2012a](#)).
- The evolution of values attached to impacts and risks extending over time (Sections 3.3.1, 3.3.2 and 3.4.3). Traditional economic theory has a difficult time calculating net present value when the probabilities of outcomes in the future are unknown ([Ackerman and Stanton, 2011](#)).

These uncertainties then feed into assessments of the costs of solutions and the benefits of various options. Many decisions, such as infrastructure standards, settlement patterns and those affecting environmental and ecological resources resonate far into the future. When these long time spans are coupled with the uncertainty regarding the impacts of climate change maladaptation becomes a risk worthy of attention ([Hallegatte et al., 2011](#)).

Of particular concern is ‘deep uncertainty’, *uncertainty that results from myriad factors both scientific and social, and consequently is difficult to accurately define and quantify* ([Kandlikar et al., 2005](#)). These affect investment appraisal in the following ways ([Jones, 2011](#); [Hallegatte et al., 2012](#)):

- analysts do not know or cannot agree on the models that relate key forces that shape the future;
- the probability distributions of key variables and parameters in these models is unknown;
- There is disagreement over the concept of problem-solution development that revolves around the perception of risk; and
- the value of alternative outcomes cannot be readily quantified and/or is contested.

The problem of rapid changes in climate, especially those affecting extremes, is not amenable to standard climate impact and adaptation assessment methods. By assessing such changes at the institutional scale, we face the issue of several problems – many measures (Section 1.2.3). Even though an institution may be able to assess a problem on their own terms, the need to avoid ‘siloes thinking’ requires decisions to be made using a range of methods, rather than any single method or model, in order to be able to negotiate the results with other actors.

Decision-making methodologies that are able to deal with aspects of climate-related uncertainty include CBA under uncertainty, CBA with real options, state-contingent CBA, robust decision-making, and climate-informed decision analysis ([Adamson et al., 2009](#); [Hallegatte et al., 2012](#)). [Hallegatte et al. \(2012\)](#) concludes that it is impossible to define the ‘best’ solution for managing uncertainty, requiring a menu of methodologies, together with guidance on which strategies are most appropriate in which contexts ([Hallegatte et al., 2012](#)). Climate-informed decision making and robust decision making ([see also Ranger et al., 2010](#)) involve a substantial stakeholder process with a strong learning capability and are more relevant to dealing with large problem uncertainty, but when outcomes are also uncertain, remain limited in their effectiveness.

The one common thread with respect to increasing uncertainty and complexity in decision-making is the importance of process. Processes uncertainties can be managed along the following themes:

- ensuring that all relevant stakeholders are involved in decision-making;
- improving partial knowledge using innovation and learning processes;
- social learning needs to be addressed at the organisational scale; and
- using a range of tools to diagnose options under different value settings.

Discount rates

Discounting in economics is used to determine the present value of future costs and benefits. Discount rates are usually positive because they reflect a preference for consumption today over consumption tomorrow (temporal discounting) – a dollar today is worth more than a dollar tomorrow. Discounting is also a measure of opportunity cost for available funds – in a growing economy, sensible investment will yield better returns than leaving the money under the mattress.

The size of the discount rate determines how much the future is discounted *vis a vis* the present². The most pertinent issue for discount rates under climate change is that of intergenerational equity. Because decisions made today will have significant impacts for generations to come, the treatment of the discount rate is crucial ([Ackerman and Stanton, 2011](#)). A discussion between researchers and Victorian decision makers concluded that the treatment of the discount rate was a critical factor for setting adaptation priorities ([Batterbury \(2010\)](#)).

The issue is further complicated because other forms of discounting affect how discount rates are used. Spatial discounting suggests what is further away matters less ([Pearce et al., 2003](#); [Shwom et al., 2008](#)). Risk tolerance and spatial and temporal inequality are only weakly correlated so need to be considered separately ([Atkinson et al., 2009](#)). [Ackerman and Stanton \(2011\)](#) argue that all analyses should include a statement explaining the choice of discount rate. They further suggest that when the case of a particular choice of discount rate is weak the discount rate should be varied and multiple results reported.

Social discount rates in Australia

In Australia, 8% SDR was used in 1991 and the Social Opportunity Cost (SOC) has been reviewed annually since then. The Commonwealth's Office of Best Practice Regulation recommends rates around 7% real (before-tax rate of return on private investment, the investment or producer rate), with sensitivity testing at 3% and 11% ([Australian Government, 2007, 2010b](#)). The NSW Treasury also recommends using a real rate of 7% (with sensitivity tests using 4% and 10%) ([New South Wales Treasury, 1997](#)). The Queensland Treasury used to recommend 6% but now requests that it be consulted over the appropriate rate (mainly to determine the appropriate risk premium) ([Queensland Treasury, 2006](#)). Infrastructure Australia recommends cost-benefit studies submitted to it should use 'real risk free' discount rates of 4%, 7% and 10% ([Infrastructure Australia, 2008](#)). The [Department of Health and Ageing and enHealth Council \(2003\)](#) recommends evaluating environmental health policies with a discount rate of 5%, with sensitivity tests ranging from 3% to 7%.

According to [Harrison \(2010\)](#), the justifications given vary; the rate is said to represent the social rate of time preference, the consumers' rate of time preference (the consumption rate of interest), the risk free rate, or the government's cost of funds. For example, the [Victorian Competition and Efficiency Commission \(2007\)](#) recommends 3.5%, 'a recent average of the ten year Commonwealth bond rate to determine the risk free opportunity cost of capital', The [Victorian Department of Treasury and Finance \(2007\)](#) endorses 3.5% (but adds a risk premium of 6% when assessing private sector

² For a full discussion of discount rates generally and as they pertain to Victorian climate change adaptation, see earlier work from this project Keating, A. and Handmer, J. (2011b) Options for assessing the cost of climate change for adaptation policy in Victoria. *VCCCAR Project: Framing Adaptation in the Victorian Context, Working Paper 2*, Victorian Centre for Climate Change Adaptation Research, Melbourne.

bids for public-private partnerships). The South Australian Treasury (2007) also uses the long-term government bond rate as a risk free rate, estimated to be 5% real. The [Department of Treasury and Finance Tasmania \(1996\)](#) recommends the long-term Commonwealth bond rate plus 1% as 'the long-term cost of funds to the Government'.

As there is no professional consensus on the value of SDR that should be used, [Harrison \(2010\)](#) suggests that the appropriate response is to conduct sensitivity analysis. The Office of Best Practice recommends using an appropriate rate to measure the opportunity cost of investment and deferred consumption ([Australian Government, 2010b](#)), and encourages full costs to be taken into account. However, it also suggests managing equity and distributional effects explicitly. It is important to recognise that cost-benefit analysis uses the yardstick of efficiency so is not structured to address such concerns ([Harrison, 2010](#)). Therefore, it is recommended that such considerations be made explicit via analysis, quantified as much as is feasible, so that alternative views are visible. Questions of equity and fairness are a policy judgement to be weighed up with other concerns rather than being a direct result of the analysis ([Australian Government, 2010b](#)).

SDRs used for recent climate change assessments ([Jones and Preston, 2006](#); [Stern and Treasury of Great Britain, 2007](#); [Garnaut, 2008](#)) are generally lower than the Australian Government's low bound of 3% for sensitivity analysis ([Australian Government, 2010b](#)). Australian government discount rates are also higher than most other developed countries when taking long-term social returns into account – we do not value the future very highly. The low SDRs used for climate change assessments, although controversial ([Weitzman, 2007b](#); [Yohe and Tol, 2008](#)), have mainly referenced mitigation. The short to long timelines, different value settings as captured in the adaptation clusters, and widely different expected rates of return on those values, suggest that appropriate discount rates for adaptation could range widely from higher discount rates linked to profitable adaptation strategies to very low or possibly negative discount rates associated with major natural systems underpinning broader social and environmental values.

Low-probability, high-impact events

Low-probability high-impact events are a challenge for climate economics ([Weitzman, 2007a](#)). Catastrophic disasters are one such possibility. Recent research also warns of the possibility of reaching a climatic tipping point that shifts the entire climate system with catastrophic outcomes for human welfare ([Lenton et al., 2008](#)). These types of events are inherently uncertain and will remain so; learning by doing or a wait and see approach are not appropriate options ([Ackerman and Stanton, 2011](#)).

A key criticism of CBA is that the significant impacts of catastrophic events are given little importance because of the low-probability of these events ([Hallegatte et al., 2011](#)). The costs associated with catastrophes can be underestimated because traditional cost assessments typically ignore (potentially non-marginal) indirect and intangible impacts, which may be profound in the case of catastrophe. As [Jotzo \(2010\)](#) points out, the threat of these events in the foreseeable future is arguably the main driver behind the current impetus for climate change mitigation and adaptation action. The CBA methodology also does not consider the value placed on security of supply of essential items such as energy, food and water.

These issues point towards a much more risk-averse approach to adaptation where the need to manage rapid changes in extremes is compatible with taking a more proactive approach to managing adverse outcomes, perhaps by seeking to transform, rather than a more conservative approach.

Intangibles

Intangible effects are those are not measurable in monetary terms because they deal with assets not traded in the market place ([Markantonis et al., 2012](#)). Frequently cited categories of intangibles include health, environmental amenity, ecosystem services, cultural heritage and community cohesiveness. The mainstream approach to intangibles is useful within the context of a CBA, however it is rarely undertaken due to resource constraints and contested methodology.

Including loss of life in a CBA is a relatively straightforward procedure. The Australian Office of Best Practice Regulation provides guidance on valuing lives in regulation appraisal for example ([Australian Government, 2010b](#)); they put the statistical value of life at \$3.5 million ([Department of Finance and Deregulation, 2008](#)). While this is widely accepted by economists it is conceptually contentious in many other arenas ([Moench et al., 2007](#)).

There is a significant literature on the methods available for valuing intangible impacts of both natural phenomena and policy initiatives. The purpose of these methodologies is to estimate the Total Economic Value (TEV) of the intangible asset that includes both use and non-use (existence) values ([TEEB, 2009](#); [Markantonis et al., 2012](#)).

Intangibles can be assessed using contingent valuation methods but this method is resource intensive, conceptually challenging and theoretically contentious ([Barkmann et al., 2008](#)). However, even conservative estimates suggest that intangible impacts are substantial. Using data on the impact of bushfire to ecosystems in Southeast Australia we estimate (Table 11), the predicted total damage cost of bushfires in Southeast Australia to ecosystem services by 2020 and 2050 ([Keating and Handmer, 2013](#)). Based on these estimates, by 2050 increases in bushfire damage in Southeast Australia to ecosystems due to climate change will have cost an additional \$1.5 billion, over and above the costs if no climate change took place.

Table 11. The predicted total damage cost of bushfires in Southeast Australia to ecosystem services by 2020 and 2050 (\$ millions) ([Keating and Handmer, 2013](#)).

Total cost	Discount rate	No climate change	Low mk2 scenario	High mk3 scenario
By 2020	i=5%	\$1,027	\$1,079	\$1,214
	i=0.01%	\$1,288	\$1,360	\$1,549
By 2050	i=5%	\$2,138	\$2,348	\$3,634
	i=0.01%	\$4,731	\$5,326	\$9,817

The valuation of intangibles is plagued by two significant ideological debates. Firstly, ecological economists argue that the possibility of trade-offs (substitutability) implied by aggregating methods such as CBA is invalid because there comes a point where we can no longer trade consumption for clean air ([Neumayer, 2007](#)). Secondly, at a deeper level many non-economists are uncomfortable with the prospect of attributing a monetary value to assets that they consider to be priceless ([Farber et al., 2002](#); [Bell et al., 2003](#)).

Markantonis' (2012) evaluation of willingness to pay for environmental services shows the broader acceptance of revealed preference (what people do) over stated preference techniques (what people say they do) in relation to current natural hazards. This method, however, is difficult to apply to future preferences.

Numerous authors continue to advocate the requirement for valuations of intangibles in both natural hazards and climate change adaptation ([Nunes and Ding, 2009](#); [Markantonis et al., 2012](#)). Studies from Australia and similar countries have shown that intangibles attract a very high value. For example, studies on flood loss show that people value the loss of memorabilia and the resulting anxiety at least as much as they value tangible losses ([Handmer et al., 2012b](#)). Stephenson's (2010) assessment of the costs of bushfire in Southeast Australia found that estimates of ecosystem services values contributed significantly to the overall disaster cost. Omission of intangible effects in economic assessment of natural disasters can lead to significant underestimation of impacts and assessment bias ([IPCC, 2012b](#); [Markantonis et al., 2012](#)).

Hard versus soft adaptation

The literature on climate change adaptation distinguishes between 'hard' and 'soft' adaptation options. Hard adaptation is adaptation via specific investments in physical assets, for example a sea wall. Soft adaptation relates to information, regulation, social behaviour and a range of institutional factors. The economic impact of soft initiatives are more difficult to estimate compared to hard options ([Agrawala and Fankhauser, 2008](#); [Hallegatte et al., 2011](#)). This may bias assessments to cost hard measures preferentially because they are more straightforward to calculate, potentially overlooking cheaper social options ([Agrawala and Fankhauser, 2008](#)).

Soft adaptations should not be ignored due to estimation difficulties because they:

- may be the most effective course of action;
- are often be more cost-effective ([Agrawala and Fankhauser, 2008](#); [Hallegatte et al., 2011](#)); and
- may be more flexible over time.

Soft initiatives may also often be complementary with hard options. In this case, assessment complexity should not be seen as a barrier, because soft options can generate considerable benefits within an overall adaptation policy; an adaptation policy that ignores institutional issues for example, is unlikely to meet its objectives ([Hallegatte et al., 2011](#); [IPCC, 2012b](#)). The use of innovation processes and of considering social and physical technology as complementary (as discussed in Section 3.2.4), is important for overcoming the separation of approaches.

Market-based instruments for climate change adaptation

Market-based instruments (MBIs), are broadly defined as *instruments or regulations that encourage behaviour through market signals rather than through explicit directives* ([Stavins, 2000](#)). [Stavins \(2001\)](#) argues that MBIs harness market forces to redefine the agenda of firms and individuals for improved environmental outcomes that are in their own self-interest. MBIs are becoming a mainstream policy instruments for managing a wide range of environmental problems like climate change, biodiversity conservation, salinity and water management in Australia and other OECD countries. According to [Whitten et al. \(2004\)](#), environmental markets are a departure from traditional 'command and control' regulation of governments and if well-designed could drive down the environmental compliance costs.

The four categories of market failures that are addressed by MBIs are: poorly defined property rights, externalities, non-standard environmental values, incomplete and asymmetric information. According to [Whitten et al. \(2004\)](#), three potential levers that MBIs are able to employ are:

- Price-based instruments that alter the prices of goods and services to reflect their relative impact. They provide certainty to industry as to the compliance costs of achieving an outcome but the environmental outcome generated to the broader community is uncertain. Examples are taxes, levies and subsidies.
- Rights-based instruments designed to control the quantity of the environmental good or service (or a suitable proxy) to the socially desired level. These instruments provide certainty as to the environmental outcome but not as to the cost to industry of achieving that outcome. Examples are cap and trade and offset systems.
- Instruments designed to reduce market friction aim to stimulate a market to produce a desired environmental outcome through improving the workings of existing markets by reducing transaction costs or improving information flows. Responses to market friction tend to be less certain and longer-term. Examples are ecolabelling or public disclosure schemes.

A number of MBIs have been developed and employed in Australia and other OECD countries. Key instrument types are shown in Table 12.

MBIs such as water trading, biodiversity improvement schemes and potentially carbon farming and biodiversity sequestration have the potential to contribute to adaptation by developing more resilient practises and systems and areas that are currently vulnerable. However, these remain controversial because of disagreements as to whether they incorporate a suitable breadth of values or merely reinforce an unsustainable status quo ([Mercer et al., 2007](#)).

Table 12. Market-based instruments by type ([Whitten et al., 2004](#))

Price-based	Rights-based	Market friction
Emission charges User charges Product charges Performance bonds Non-compliance fees Subsidies (materials and financial) Removal of perverse subsidies/taxes Deposit-refund systems	Tradeable permits, rights or quotas Offset schemes	Reducing market barriers Extension / education programs Research programs designed to facilitate market exchanges Labelling Information disclosure

Transformation

The modelling and valuation methods described above are largely suited to assessing economic changes at the margins of current systems. It may be the case that some places and/or sectors in Victoria may have to undergo significant transformation³ or bifurcation in light of climate change impacts. Examples include the moving of an entire population due to unacceptable risk of natural disasters or the shifting of an entire industry due to the present geographical region becoming unsuitable for production ([Aaheim and Aasen, 2008](#)). These changes are not marginal and as such the economic techniques described here would have difficulty assessing them. Although they cannot be easily assessed by dominant assessment methodologies such as CBA ([Hallegatte, 2011](#); [Hallegatte et al., 2011](#)).

Summary

Since the completion of the basic general equilibrium model in the 1950s, a massive volume of theoretical work has been undertaken to explore the consequences of varying the assumptions underlying this model. Two general conclusions seem to have emerged clearly from the work briefly reviewed in this section. Firstly, the basic neoclassical model is not robust, in that quite different results emerge from small variations in assumptions. Secondly, perfectly good models can be built with a wide range of differing assumptions, none of which can claim to be a preferred representation the economic world. Thus there is no longer one preferred model but rather many models, each appropriate for different circumstances. The implicit goal of a single explanatory model of the economic system now looks implausible, while the value neutral foundation of individual preferences or utility has been shaken.

Where this leaves the issue of adaptation to climate change is that there is no single model that can address the full reality of the situation, but many tools which can assist in specific-defined situations. Many approaches to the economics of adaptation to climate change start from the basic model, but add specific tools to it to address perceived problems. These will be review below. But what seems to be needed is a broader framework which would allow diverse theories and models to be utilised as circumstances dictate, to understand adaptation challenges and to develop appropriate policy responses. The work of Ostrom ([2005](#), [2007a](#), [2011](#)) provides such a framework.

The distinction between frameworks, theories and models within the IAD architecture is critical. The framework needs to be sufficiently general to allow for a richer ontology and for the wide range of economic and social characteristics that are observed empirically. This means many different economic and social theories can be accommodated within the framework. The problem-solution-implementation framework can be used to place these findings within a decision-making process.

³ IPCC (2012, pg. 3) defines ‘transformation’ as “The altering of fundamental attributes of a system (including value systems; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biological systems).”

Table 13. Comparison of neoclassical and the extended IAD framework.

	Simple Neoclassical Model	Extended Ostrom IAD Framework
<i>Ontology</i>		
Organisation	Market and government	Polycentric forms of governance
Types of goods	Public and private	Four types of goods (including common pool and toll goods)
Agents	Profit maximising firms and rational individuals	Diverse theories/motives for human and organisational behaviour
<i>Characteristics of economy and society</i>		
Information structure	Full and complete information	Allow for limited and asymmetric information, uncertainty and bounded rationality
Production technology	Diminishing returns to scale	Possibility of increasing returns to scale and scope
Interaction between agents	Agents interact only through prices/markets	Allow for many forms of interaction, including cooperation and trust
Coordination	Coordination is achieved through prices and the market	Agents may fail for many reasons to achieve coordination; opportunities are lost
Path dependence and lock in	Given other assumptions, no issues of path dependence	Various factors may generate path dependence, which may lead to lock-in of successes or failures

3.4 Evaluating the solutions

3.4.1 Valuing adaptation

So far in this report we have established the following framings towards valuing adaptation:

- We take a whole of climate approach to valuing adaptation where the current adaptation deficit to climate change plus variability is contrasted with future deficits.
- Adaptation is being assessed at the institutional scale rather than within the context of event, location or sector-based approaches.
- Critical decision points are when risks cross domains, where the risk itself has amplified beyond critical threshold and/or the responsibility for responding to that risk has crossed domains.
- Adaptation needs to consider avoiding or mitigating the impacts of such damages occurring in future under rapid change. Disaster risk reduction techniques provide a useful starting point for such deliberations.

The economic framework for decision-making we apply has three phases:

1. The first phase involves valuing impacts using adaptation clusters as a valuation framework. Such assessments are generally scenario-driven, where scenarios can range from being climate, to operational to policy scenarios. The resulting values can range from direct monetary impacts through to intangibles measured using qualitative methods. This brings an assessment to the stage of assessing values at risk, informing the decision as to whether adaptation needs to be planned. A range of values may be assessed and ranked according to a given set of criteria using ranking techniques or multi-criteria analysis.
2. The second phase proposes and costs a range of adaptation options. Scenarios to propose, sort and select options can be applied at this stage. These can be costed as part of CBA, cost-effectiveness, various ranking strategies such as

gauging stakeholder preferences or merely follow from the previous phase if a political decision has been made to act. The choice then concerns which action to take. Full cost-analysis will take in the cost of R&D to develop and evaluate the adaptations, and to implement and maintain them over time.

3. The third phase then selects the actions to take (including processes and methods for implementation), by considering the costs along with potential benefits. If outcomes can be diagnosed with any reliability, then various permutations of CBA can be applied, multi-criteria analysis, or robust decision-making. Benefits are measured using institutional values. In this context, efficiency, the principal outcome for orthodox economics is one of many institutional values that include equity, fairness, transparency, justice and so on. The choice of such values by which to assess benefits will also self-select potential valuation methods. If outcomes cannot be projected, because the solution pathway is observed by uncertainty, process-related values applied using innovation models will dominate.

The methods and tools for carrying out these three steps are briefly summarised in Section 3.4.3. The project workshop *Beyond the Mean*, where we trialled this approach is reported on and summarised in Section 3.4.2. The process-related aspect of evaluating and implementing adaptation is described in Section 3.4.1. Transformation and maladaptation are considered in the following two sections. Developing capacity and supporting governance are summarised in Section 3.4.7 and finally, resulting policy considerations are summarised in Section 3.4.8.

3.4.2 Project workshop *Beyond the Mean*: synthesis and results

A workshop for the project, *Beyond the Mean: Valuing Adaptation to Rapid Change* was held at Victoria University on November 30. Over forty people from diverse institutional backgrounds participated. The recipients received a context paper that framed a set of scenario exercises looking at the economics of adaptation, rapid climate change, the propagation of risks across domains, risk ownership and potential adaptation options.

A pre-scenario exercise looked at the impact of recent extreme events with reference to four introductory presentations on the economics of adaptation, rapid climate change and the economics of disasters. Consistent responses from the workshop were:

- The risk of climate change is not adequately valued because it is not well-understood;
- Media plays a key role in how an event or risk is understood and valued;
- Political objectives currently override reality;
- The need to stay in 'comfort zones' is a major barrier to change; and
- There is a need for a cross-sectoral, whole-of-organisation approach to managing these disasters.

Scenario exercise

A scenario exercise examined rapid changes in extremes in urban to peri-urban, rural and national settings. The impacts of those events were then traced over multiple time lines across a range of public and private institutional domains. The first part of the scenario exercise grouped impacts and risks into short, medium and long-term risks and mapped them into local, state and federal government domains, private domains and identified un-owned risks. Impacts were identified in the first exercise, but these

were later converted into risks by attaching values linked to one or more adaptation clusters, described in Section 3.3.4.

The resulting risks were then ranked and the most important was used to propose and value adaptation strategies. The following tables show the first and second exercise from each of three scenarios (six of twelve total produced by the workshop).

The scenario exercise applied a process that was both simple and complex. The complexity was in combining two differently structured models within a single system; most people work with both but are usually aware of only one. These models were:

- A cause and effect model that traced climate events along a time line through impacts to risks. It followed a linear line of reasoning (although the system it describes is not); and
- An institutional framework that has a variety of purposes (e.g., policy, profit, lifestyle, community values). Some institutions have direct responsibility for managing particular risks; others have separate aims that are affected by climate risks. This system is recursive, in that any actions taken will affect the system itself.

Risk was expressed differently within part 1 and 2 of the exercise:

- In part 1, event-based risk was expressed through the cause and effect model and expressed as hazard times exposure; that is, a combination of climate events and the systems those events impact upon. Thus the workshop identified impacts and resulting values at risk. The subsequent aim was to trace these values along time-lines and across different domains; and
- In part 2, we were interested in addressing solutions to a prioritised risk with respect to the aims and responsibilities of relevant institutions across time frames.

Because of the high uncertainty within the system of cause and effect, the accurate scientific prediction of climate-related impacts is not always possible, so scenarios were used to bridge the gap between impacts and risks identified in Part 1 and the institutional goals and solutions in Part 2.

These scenarios were given to each group who were then free to embellish them in social and physical terms to create an internally consistent narrative underpinning their assessments of how impacts and risks may play out.

Some of the scenarios used are detailed below:

Large Regional Basin Scenario 2

The drought of the century through to 2044 has been broken by two La Niña mega events in succession in 2044 and 2045. The first set up some major floods that were manageable and greeted with great cheer. The second saw record falls over Queensland and the eastern states. Three major floods occurring over August to January saw massive inundation in all major rivers of the basin.

Cuts to roads, rail and power have isolated many regions for the first time. Crop and stock losses are unprecedented. Dengue fever has been detected in the northern part of the basin and Ross River Fever and Murray Valley Encephalitis are widespread. Emergency food drops and medical flights are being made across the basin. After the

devastation of the drought then the floods, recovery will be protracted. Depleted groundwater supplies mean that drinking water, apart from tank water, is at a premium.

Metro peri-urban region scenario 2

In 2045 a series of major storms in a wet, La Niña year resulting in combined flooding and storm surge that inundates low lying coastal suburbs. Major flooding occurs in the inner urban riverside zones and refuses to drain under the pressure of storm tides and floodwaters coming downstream. Numbers of people are stranded in high rise apartments. Many buildings inundated by sea water have absorbed permanent damage.

Low-lying coastal infrastructure and pipe systems have taken on sea water, and become damage due to soil movements affected by changes in groundwater pressures.

A hail storm occurring in the same season has cause large amounts of property damage, destroying the odd Mercedes. A series of rainfall and storm events on saturated urban catchments have led to successive flash flooding in the same locations, in some places, three times in the same year.

National scenario

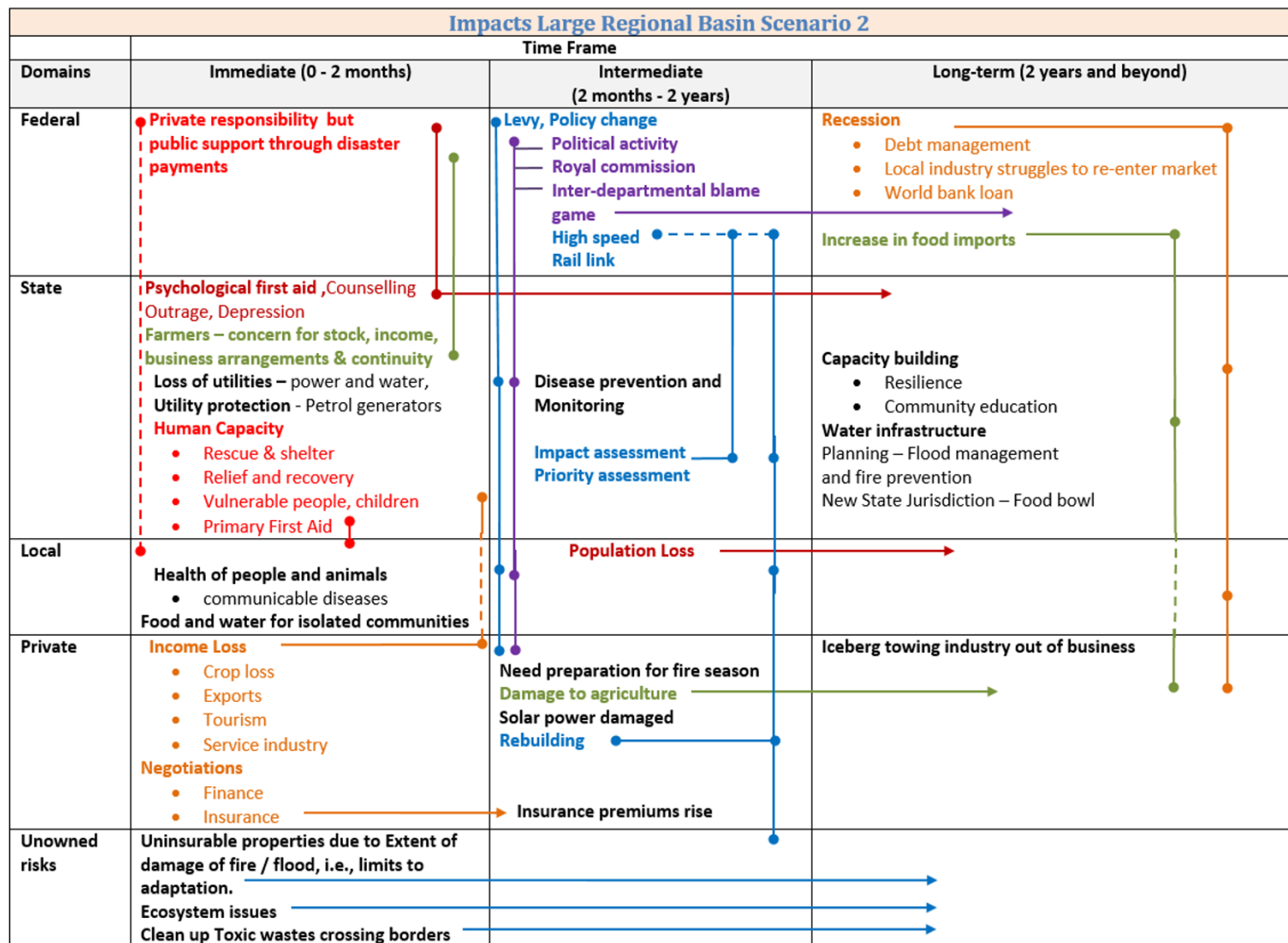
The events of the mid to late 2030s and early 2040s, with droughts and heat stress affecting both urban and rural regions, followed by the one-two punch of successive La Niña events.

The drought, covered in the Metro and Basin scenarios was protracted, causing large declines in urban water supply, and successive wildfires in the urban centres of the south-east, including one event in The Dandenong's that claimed over 500 lives. The floods have affected every east-coast state, but the south-west remains very short of water and continues to be affected by drought and bushfire.

Another feature of La Niña events is the occurrence of landfall tropical cyclones. Two cyclones, Cyril and Eric have crossed the Queensland coast. Cyril took out the Gladstone Port facilities, and Brisbane has finally experienced its long-awaited tropical cyclone, a force four. The Galilee Basin coal field has closed due to flooding. The gas fields of the North-west shelf is on full alert, and the potential loss of gas supply if a tropical cyclone does score a direct hit has been labelled a potential national emergency.

The results in the following tables summarise the results of the exercise.

Source: Young, C.K. and Jones, R.N. (2013) Beyond the Mean: Valuing Adaptation under Rapid Change. Workshop Report, Centre for Strategic Economic Studies, Victoria University, Melbourne.



Large Regional Basin 2 Risk: loss of quality of life and lack of food security

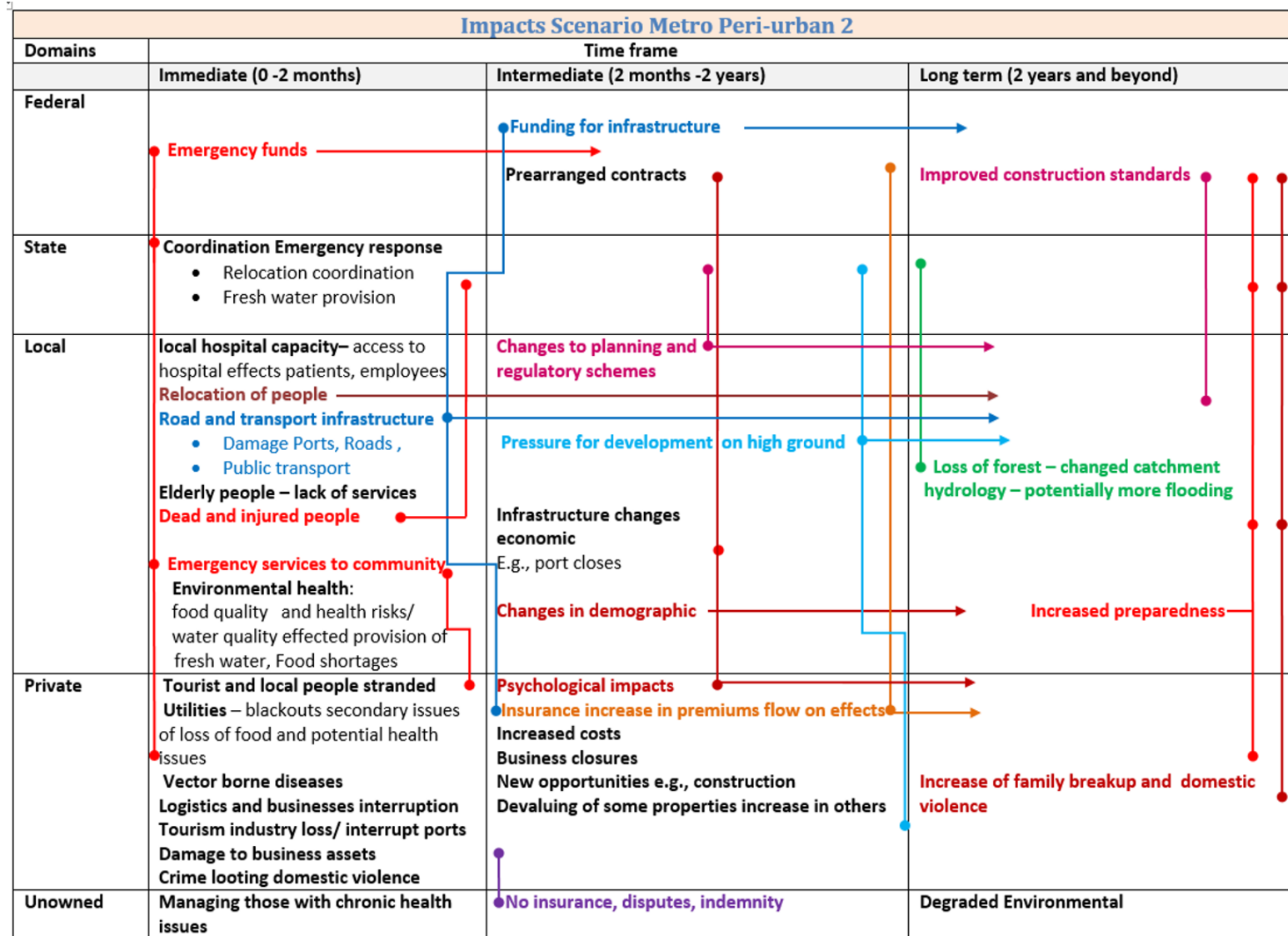
Who is responsible for developing and implementing adaptations?
What resources do you need and who provides these?

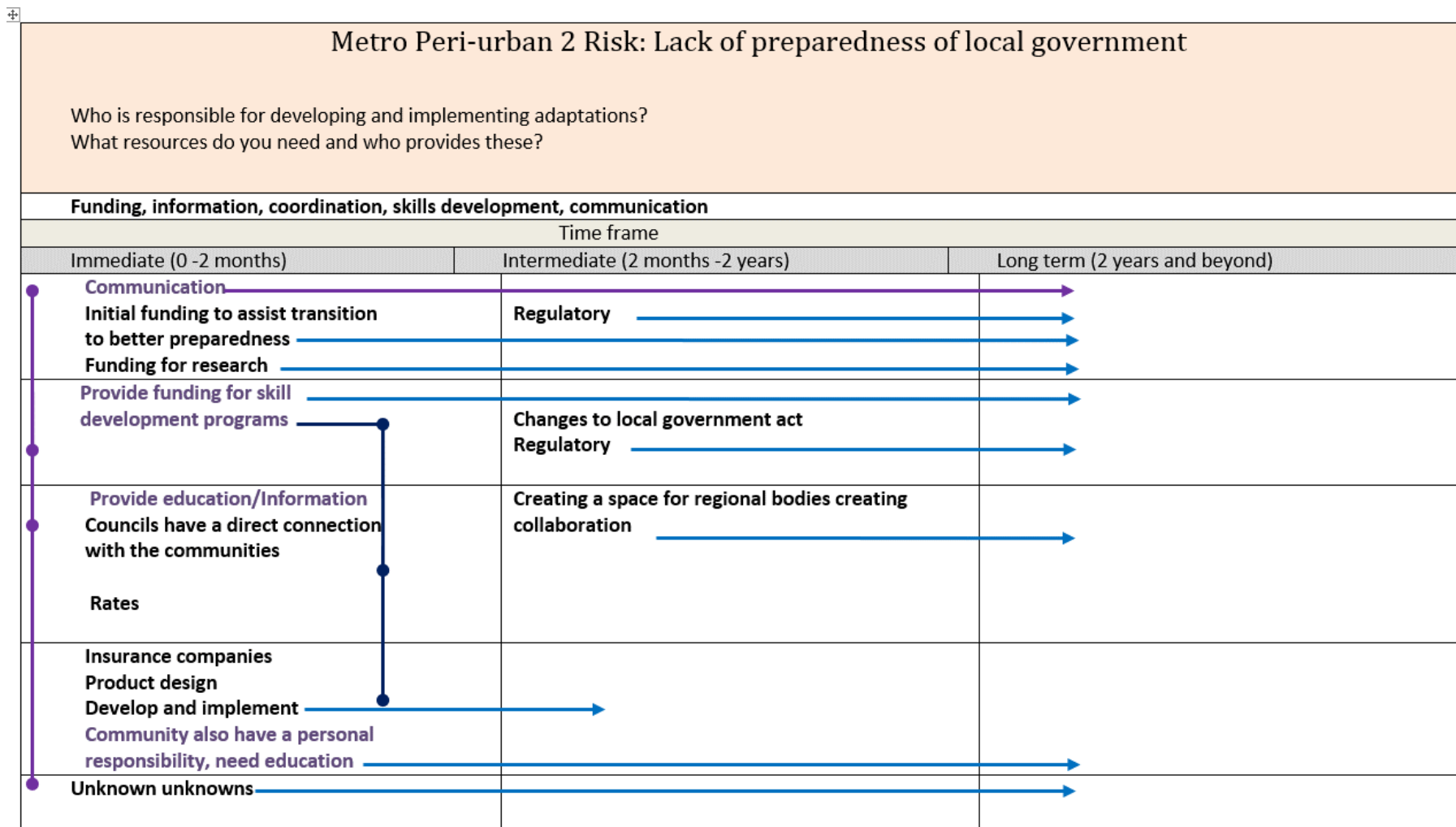
Key needs	Employment, policy, funding, education		
Domains	Time Frame		
	Immediate (0 - 2 months)	Intermediate (2 months - 2 years)	Long-term (2 years and beyond)
Federal	Water use Tertiary education NBN National facilities Industrial policy Planning welfare	Water planning Reserve fund Public + Private Social returns	
State	Policy Educational opportunities Health		
Local	Infrastructure – services, amenities Land use planning Cultural and community development planning Community consultation		
Private	Goods and services Employment Financial investment planning	Tourism	
Unknown risks	Migrant groups Volunteerism Altruism Community attributes Funds?		

Values to be sustained by above adaptation strategies are:

People : Protect the human life, employment and general well being

Environment: Sustain the food bowl





Key note: Being prepared would include being prepared to be able to maximise the opportunities that extreme events offered for change. Also people would need to do ‘more with less’ across all domains.

Values to be sustained by above adaptation strategies are: Equity, Community connectedness/continuity and reputation.

Impacts Scenario National (Table 1)			
Domains	Time frame		
	Immediate (0 - 2 months)	Intermediate (2 months - 2 years)	Long term (2 years and beyond)
Federal	Central coordination state of emergency Armed forces disaster relief Disaster relief funds (if available after the Previous events).	Government of governments <ul style="list-style-type: none"> Budget revision How much reserve do we have? National transport system National management essential services National parks and heritage Export Strategy Rebuilding Triage	Industry assistance adjustment International environmental Agreements
State	Public accounts in disarray	Loss of taxable income Building standards	
Local	Infrastructure recovery and hardening Water restrictions	Tourism activities curtailed	
Private	Energy security	Migration Rebuild	Insurance market intervention Disruption Agricultural production
Unowned	Households under insurance Household accounts in disarray	Reduced consumption as consumer confidence effected	

National (Table 1) Risk: Social Vulnerability

Who is responsible for developing and implementing adaptations?
What resources do you need and who provides these?

Key needs	Long term budgetary resilience in public and private finance/taxation reform		
Domains	Times frame		
	Immediate (0 - 2 months)	Intermediate (2 months - 2 years)	Long term (2 years and beyond)
Federal	Change of expectation of budget function, government role Political capital/social license	Taxation reform, change to incentive structure Risk sharing, classification and spreading. 3rd party risk sharing (e.g., government not self-insuring)	
State			
Local			
Private	Private business and households investment and savings		
Indeterminate	International capital and finance		

Key note: budget resilience is path dependent and likely to require significant social and political change.
Values to be sustained by above adaptation strategies are: budgetary resilience in private and public sector

Results

One hundred and seventy-six primary impacts were identified across the six scenario groups. Groups were also asked to allocate impacts across three time lines:

- Immediate (0–2 months);
- Intermediate (2 months – 2 years); and
- Long-term (2 years and beyond).

Allocations were shared fairly evenly across time frames.

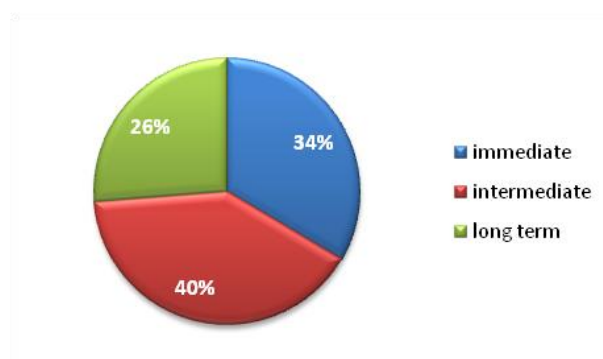


Figure 22. Allocation of time scales to 176 primary impacts.

Multiple time scales were allocated to 17% of total impacts. The predominant time scale allocated was intermediate – long-term with 45% – with intermediate to long-term being 39%. The lowest allocation was immediate to intermediate.

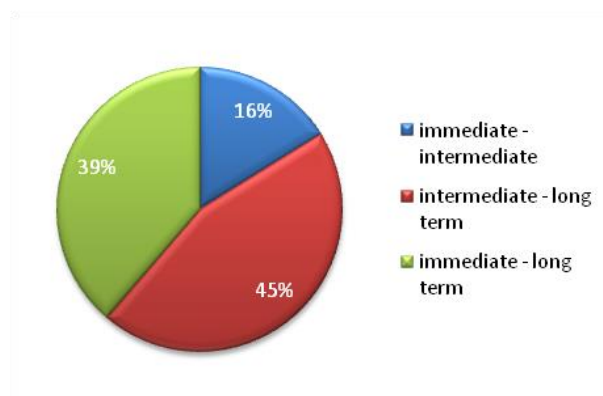


Figure 23. Breakdown of multiple time scales to 30 lasting impacts

Groups were asked to allocate impacts to four domains:

- Local Government;
- State Government;
- Federal Government; and
- Private (including community and industry).

They were also asked to list any impacts that could not be assigned to an institutional domain as un-owned. The largest number of impacts were allocated to the private sector 28%, and 7% of the impacts were un-owned. The rest of the risks were distributed across Federal Government (21%), State Government (23%) and Local Government (21%). The largest group of un-owned impacts were social assets, but types were widely shared across natural assets and capital assets as well as being legal and governance-related.

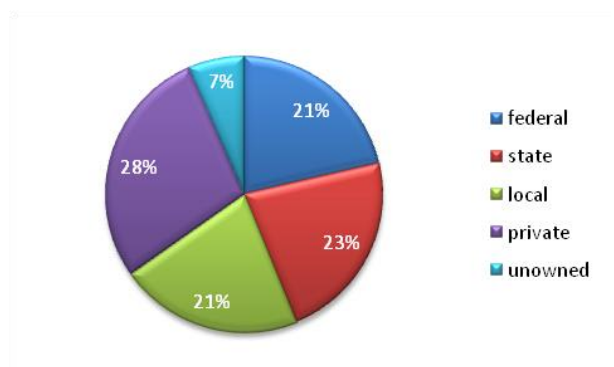


Figure 24. Assigned domains to a total of 176 impacts

Although the majority of impacts were allocated to single domains, 38% of impacts were explicitly allocated to more than one domain. These are the identified cases of risk crossing domains by each group. Many others identified as occurring at state or national scale will implicitly also affect smaller-scale domains.

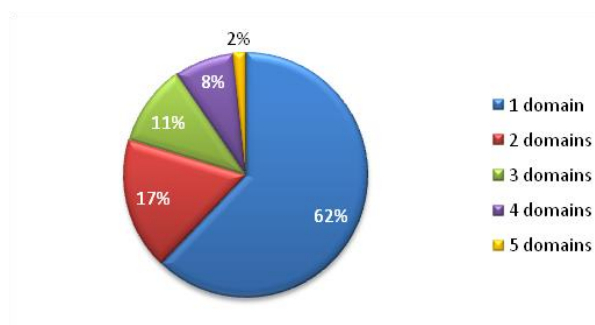


Figure 25. Number of domains assigned to a single impact.

Values were attached to these impacts by linking them with adaptation clusters. There was no limit on the number of clusters that could be linked to any single impact. The most prominent cluster was Social Assets and Infrastructure (36%) and the smallest allocation was Natural Assets and Infrastructure (10%). The remainder were: Goods 15%, Services 20% and Capital Assets and Infrastructure 19%.

Allocations to adaptation clusters across the different scenarios are shown in Figure 26. These show the strong emphasis on Social Assets and Infrastructure, with Capital Assets and Infrastructure being close behind.

These findings show that 'soft' socially-constructed values were more prominent (46%) as 'hard values' that can be allocated to the monetary economy. Such soft values were identified as being highly relevant for policy-making, in addition to being vulnerable to risks crossing and amplifying across domains. Some of the most prominent were those that related to community wellbeing such as livelihoods, mental health and community cohesiveness.

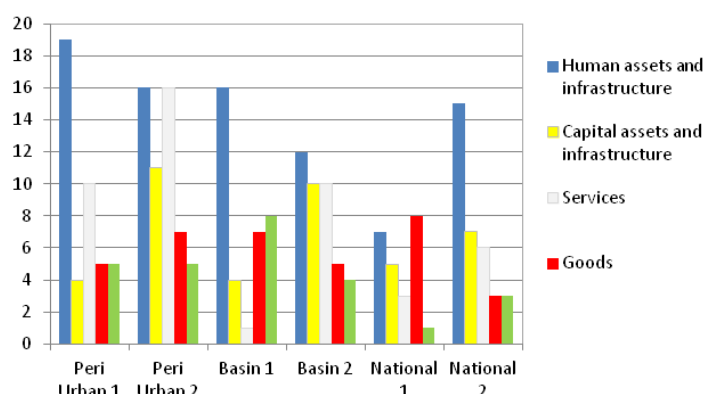


Figure 26. Adaptation clusters assigned to impacts across the six workshop groups.

Solutions

Groups were asked to select the most prominent risk to use for the solution exercise and were then asked to consider the following questions in relation to the selected risk:

- Institutionally, who is responsible for developing and implementing adaptations?
- What resources do you need and who provides these?
- What values are you sustaining through these adaptations?

Some participants found this more challenging than the previous impacts identification exercise. This was partially due to the exercise being the last in a full day, but it may also indicate that this is an area of non-linear problem-solving where capacity needs to be developed.

Table 14 summarises the core needs and values being sustained. Those values are complex, society-wide values that would not be out of place in any general strategic setting addressing issues of sustainable development.

Groups were asked to allocate responsibilities across three time frames:

- Immediate (0–2 months);
- Intermediate (2 months – 2 years); and
- Long-term (2 years and beyond).

The intermediate time frame received the largest allocation (45%) and long-term responsibilities the smallest (19%), with 36% of responsibilities being allocated to immediate action. Almost one-third (29%) of responsibilities were allocated across multiple time frames.

Table 14. Core needs and attributed value of key risk by scenario.

Scenario	Key Risk	Core Needs	Values being sustained
Peri-Urban 1	Water and electricity security	Communication, financial incentives, policy, evaluation	Security of key infrastructure – water and energy. Community continuity
Peri-Urban 2	Lack of Preparedness of Local Government	Communication, Funding, coordination, information, skills development , research	Equity, Community connectedness/continuity and reputation
Basin 1	Lack of coordinated responsibility working towards adaptation	Development based policy, governance - responsibilities, research, funding support, monitoring and evaluation	Economic benefits to share including productivity, wellbeing and profitability, security
Basin 2	Loss of quality of life and lack of food	Employment, policy, funding, education	People: Protect the human life, employment and general well-being Environment: Sustain the food bowl
National 1	Social vulnerability	A resilient budget Public and private tax reform	Budgetary resilience in private and public sector
National 2	Disrupted utilities/critical infrastructure	Communication, Research based information, regulation, investment , innovation, political will	Consistency, our way of living

For the allocation of responsibilities, the Federal Government was given the largest (26%), industry was slightly lower (23%) and both state and local government were allocated 20%. Eleven per cent were indeterminate.

These responsibilities varied widely:

- Addressing unknowns;
- Threat of people not understanding water is everyone's business;
- Threat of people not understanding the role of research organisations;
- Migrant groups;
- Volunteerism;
- Altruism;
- Community attributes;
- Funds;
- International capital and finance;
- Who is responsible for effective communication and the tools that are needed?;
- Willingness to act cooperatively – political will/community education;
- Information and analysts; and
- Influence of younger generation.

Many of these are diffuse, economic intangibles and relate to perceptions of risk and value. One fifth of responsibilities were allocated across domains (21%). Particular values included:

- Security;
- Equity;
- Community;
- Continuity and consistency;
- Connectedness; and
- Resilience.

These values could be considered as the institutional values of the community within the IAD framework.

Workshop outcomes

The workshop clearly viewed the issue of adapting to rapid change, where significant risks are crossing domains, and of adapting to those risks, through the lens of addressing society-wide values. The following needs were identified on the day:

1. The need for capacity-building across public and private sectors in relation to long-term planning and development of long-term, multi-party policies;
2. The importance of diversity of input when considering these issues. Who is in the room has a strong influence on the outcomes;
3. The need for collaborative mechanisms that enable bottom-up, top-down interactions driven by the reality of what is happening – enabling dialogue rather than debate;
4. The need for relevant data but also to value the usefulness of existing information;
5. Tools to assist understanding how to value and cost intangible aspects of adaptation;
6. Greater consideration of how impacts, such as psychological impacts of extreme events, can amplify over time if not addressed;
7. Mapping of communication and information needs across public and private sectors;
8. Proactive policy responses to address events before they happen.
9. Governance to address un-owned risks, manage risks across domains and deliver resources where they are needed; and
10. Research to better understand:
 - Interactions between social, economic and natural systems, where the thresholds are for particular impacts and at what point they cross into other domains;
 - The skills and tools needed to better prepare for these events, particularly in relation to the valuing of intangible costs associated with rapid change over the long-term;
 - The value and cost of primary and secondary impacts across different domains and time frames; and
 - Which impacts and risks amplify over time and how they amplify.

Addressing rapid climate change at the institutional scale is challenging. Although participants engaged willingly in the exercise for the most part, developing solutions is clearly a difficult task with only a limited number of existing examples to work from.

The workshop supported the notion that adaptation to changing climate risks should be integrated into existing institutional roles, rather than being a separate exercise. The current institutional capacity to do this, however, was seen as limited.

3.4.3 Evaluation criteria

Economic narratives reinforce stable if not rigid arrangements that affect society's resilience in situations of rapid ecological change ([Röling and Maarleveld, 1999](#)). The economics of dealing with multiple system values and rapid changes that are difficult to model have been largely ignored in favour of a simplified system that is tractable in modelling terms but is unlikely to adequately address the risks of rapid climate change.

In orthodox economics, values, costs and benefits are interchangeable, maintaining the same values over time as future costs and benefits are discounted from the present. The real world of values is much more complex, and for that reason we have separated the economic evaluation process into three parts in order to allow a variety of different methods to be used.

They are (from Section 3.4.1):

- The valuation of impacts and associated system variables;
- The evaluation of different adaptation options or strategies based on cost and other considerations; and
- The valuation of benefits.

We outline the applicability of selected economic decision-making tools that have been proposed or used for climate change adaptation, particularly for managing uncertainty. Attention is drawn to the implications of rapid change for the applicability of these tools.

Valuation methods for impacts

A wide range of valuation methods are in circulation. The methods described in [OECD \(2006\)](#) provide a comprehensive description of different valuation methods for use in CBA, but these are all stand-alone methods that can be used separately.

Balance sheet methods

Time series of income-expenditure data normalised for climate can provide evidence of the effect of direct impacts on income. For a number of impacts, input-output tables can be constructed and analysed using econometric methods. Time series containing disasters or abrupt changes in external variables can be used to assess the impacts of shocks.

Spatial and temporal economic geographies of economic sensitivity or exposure to hazard can also be constructed from insurance data, disaster costing's or general economic data (Section 3.1.8). These can contribute to vulnerability assessments and assess values at risk ([Jones and Webb, 2008](#)). These methods favour impacts that are well-integrated into the conventional economy, but can be augmented by preference methods or shadow pricing.

Stocks and flows

The physical economy is an important source of value, particularly for environmental stocks and flows that are not well represented in the monetary economy ([Turner et al., 2011](#)). Integrated models of stock and flows can be used to assess the impacts of

climate change in complex settings, producing estimates of physical impacts to which monetary values can be attached ([Turner et al., 2007](#)). This type of system is amenable to analysing shocks.

Computable general equilibrium modelling

Computable general equilibrium models are almost certainly incorrect in their assumptions but can be useful in specific circumstances. They provide useful information around the flow-on effect of extreme events in the economy; an example being the 2010–11 Queensland floods ([Hartley et al., 2011](#)), and also on trade effects of different impacts. Their basic assumption of marginal change from equilibrium means they are unable to provide meaningful estimates of future impacts other than in a qualitative way.

Shadow pricing

Shadow pricing methods estimate the value of an asset or commodity by the benefits associated with closely linked economic variables. For example, property prices are higher near open space providing shadow prices for the benefits of open space amenity in urban settings ([Hatton MacDonald et al., 2010](#)). It is a method for assessing mean conditions and not suitable for assessing rapid change. However, it has great potential for assessing the co-benefits of adaptations where social and environmental outcomes are important.

Expert assessment

One way to gauge impacts and value where models aren't available or are too resource-intensive is to interrogate experts in a structured manner producing a conclusion with a given range of uncertainty that can act as a vote of confidence in the underpinning theory, data and models – albeit through a socially-influenced filter ([Brooks et al., 2005](#); [Doria et al., 2009](#)).

Preference methods

Three formal methods for eliciting value preferences are willingness to pay, willingness to avoid damages, which are both stated preference methods (what people say) and survey of how people behave in given circumstances, or revealed preference. These methods are subject to framing effects where the first two are asymmetric but measure the same thing ([Bateman et al., 2009](#)) and the second only deals with past but not future values.

Aligned with this are a range of survey methods that can elicit peoples' psychological and cultural preferences in order to better understand social and cultural influences on valuation linked to adaptation preferences ([Reser et al., 2011](#)).

Cost and benefit methodologies

Probabilistic CBA is used when subjective probabilities can be assigned to input assumptions, Real options techniques, also called sequential analysis, minimize the 'cost of error' caused by uncertainty ([Hallegatte et al., 2011](#); [Dobes, 2012](#)). State-contingent CBA also builds flexibility into adaptation ([Adamson et al., 2009](#)), where different activities designed to maintain maximum returns or bolster resilience can be triggered based on a given set of signals. Again, this methodology is suitable for assessing rapid changes in conditions, but diagnosing the correct set of signals would be paramount.

The largest limitations of CBA are that it is restricted to situations that involve one, or a few decisions, and that it requires sufficient information about the potential benefit to be computable.

Costing and evaluation methods

Cost-effectiveness analysis

Cost-effectiveness assesses the cost of acting without specific assessments of the resulting benefits. This may be for the following reasons:

- An *a priori* decision has been made on the basis of expediency or for political considerations, and the cheapest or most effective option is being sought.
- That the benefits are self-evident and cost-effectiveness is common sense.
- The benefits and costs are incommensurate, but that costs are perceived as being less than the potential benefits over the long-term. This consideration is most relevant to environment and social assets.
- That the benefits of different options are considered roughly equivalent.

Ideally costing will look at the whole project cost from R&D through to implementation. A weakness of this approach is that often the different options may themselves be incommensurate and the relative benefits uncertain, so 'effectiveness' is very difficult to measure. An example is where a town vulnerable to sea level rise, storm surge and groundwater contamination may weigh up building a sea wall and safeguarding groundwater supplies as opposed to relocation.

Multi-criteria analysis

Multi-criteria analysis (MCA) is extremely flexible in approach. As a fully quantitative technique it will score options according to various criteria, resulting in a combined score that identifies the most optimal outcome. At its most qualitative, it can involve a room full of people with a given set of criteria making a subjective selection from a set of proposals.

This latter form of MCA and variants using hybrid methods that combine quantitative estimates with subjective judgments is probably the most common form of evaluation used in adaptation assessments. At this level, it is vulnerable to the social constructions of the stakeholders making the collective decision. By conducting an institutional analysis (where the respective values of the different participants are made explicit in addition to the institutional value at play), much more well-informed decisions can be made.

While a room full of people making a decision can look very imprecise, if they are informed by analyses of value consistent the methods above and a rigorous analysis of the hidden values and assumptions being used at the organisational and institutional level is facilitated, the MCA can be very useful.

Robust methodologies

Robust decision-making approaches seek optimality for a given situation or best-guess outcome, but instead seek decisions that will perform well over a wide range of plausible climate futures, socio-economic trends, and other factors ([Dessai and Hulme, 2007](#); [Groves et al., 2008](#); [Wilby and Dessai, 2010](#); [WUCA, 2010](#); [Brown et al., 2011](#);

[Lempert and Kalra, 2011](#)). Robustness criteria can often illuminate trade-offs that help decision-makers achieve consensus on actions, even when they do not agree on expectations about the future ([Lempert and Collins, 2007](#)). Resilience tends to describe a property of systems, which might be affected by decision-makers' choices ([Folke et al., 2010](#)), while robustness is a property of the choices made by those decision-makers. Methods also exist to summarise trade-offs for decision-makers for multiple objectives and values, and at higher levels of uncertainty, by exploring decisions that are robust over many futures and objectives ([Kasprzyk et al., 2013](#)). Robust decision-making can also be used to satisfy a range of institutional values inherent in the operation of a system, satisfying criteria such as distributional equity, procedural fairness and affordability in the case of water or energy.

The process of robust decision-making is a collective process that brings stakeholders together in dialogue regarding values, vulnerabilities, performance metrics and acceptable risks ([Hallegatte et al., 2012](#)). The use of multiple scenarios allows the possibility of scenarios representing extreme events ([Hallegatte et al., 2012](#)) that can easily test different realisations of plausible rapid change. Such testing would also be able to investigate system resilience, investigating the potential to enhance that resilience and respond better to future events.

Robust decision-making is resource-intensive and the stakeholder process can be unpredictable. If quantitative modelling is being used with a wide range of scenarios, this can also be resource-intensive ([Kowalski et al., 2009](#); [Hallegatte et al., 2012](#); [Ranger and Garbett-Shiels, 2012](#)).

Bounded cost and trade-off methods

Situations may be resource-constrained where there are only a certain amount of resources available to adaptation, or where low-risk and broadly effective solutions are preferred over others that may be unfamiliar, or high-risk but potentially more effective.

Low-regrets

Low-regrets approaches (sometimes called no-regret) have net benefits under all climate scenarios, including current climatic conditions ([Hallegatte, 2009](#); [Hallegatte et al., 2012](#)). For example, increased disaster risk reduction would have a benefit today and under all future climate scenarios.

Satisfying over a wide range of futures

Low-regrets adaptations described above are a subset of robust approaches that are widely-recognised ([Productivity Commission, 2012](#)) to be a suitable starting point for adaptation investments. Extending the idea of low-regrets adaptations that are of benefit now and under future scenarios, we can utilise formal robust decision-making approaches that are designed to be acceptable under a wide range of futures ([Lempert and Collins, 2007](#)).

Safety margin strategies

Safety margins incorporate a low or no-cost measure within a design that enables it to operate under changed conditions in future, commonly known as head room.

Soft adaptations

Soft adaptations can offer more flexibility than hard adaptations, so may be able to manage a wide range of conditions. They are more difficult to predict and cost, so require measures of social rather than economic performance to evaluate and sustain. For example, warning and evacuations combined with insurance may be cheaper in areas subject to storm-tides than dikes and sea walls, and can be readily adapted to new conditions ([Hallegatte et al., 2012](#)).

Reduce decision time horizons

Reducing the operating lifespan of investments is a way of managing uncertainty in a changing environment ([Hallegatte et al., 2012](#)). Shorter-lived and cheaper buildings in sea level rise affected areas with managed retreat are two examples.

Evaluating benefits – environmental accounting

Systematic undervaluation of the environmental services and resources is an ongoing problem. The need to measure and incorporate environmental assets into the broader social asset base was emphasised by [Stiglitz et al. \(2009\)](#):

'What we measure affects what we do; and if our measurements are flawed, decisions may be distorted. Choices between promoting GDP and protecting the environment may be false choices once environmental degradation is appropriately included in our measurement of economic performance. So too, we often draw inferences about what are good policies by looking at what policies have promoted economic growth; but if our metrics of performance are flawed, so too may be the inferences that we draw.'

Recently, the [ABS \(2012\)](#) published *Completing the Picture - Environmental Accounting in Practice* describing how environmental accounts can be used to improve decision-making processes for a range of processes including adaptation to climate change. The System of Environmental-Economic Accounting (SEEA), which was elevated to an international statistical standard in early 2012, is used as the basis of these accounts. The SEEA framework links information on the economy and the environment to provide a range of useful metrics and an integrated database for policy analysis and decision-making ([ABS, 2012](#)).

Four main types of accounts in the SEEA framework are added to the existing monetary stock and flow accounts of the System of National Accounting:

- *Physical flow accounts* record flows of natural inputs from the environment to the economy, flows of products within the economy, and flows of residuals generated by the economy (including water and energy used in production and waste flows to the environment);
- *Functional accounts for environmental transactions* record the many transactions between different economic units (i.e., industries, households, governments) that concern the environment;
- *Asset accounts in physical and monetary terms* measure the natural resources available and changes in the amount available; and
- *Ecosystem accounts* are structured to summarise information about complex plant, animal and micro-organism communities, their non-living environment interacting as a functional unit and their changing capacity to operate as a

functional unit and their delivery of benefits to humanity. These accounts are not yet part of the international statistical standard.

These different accounts can be used to measure changes in environmental stocks and flows to assess both impacts and progress in adaptation ([ABS, 2012](#)). In particular, they address monetary flows to adaptation, mainly using transactions relating to environmental protection. New methods based on SESA are being developed to set up separate adaptation accounting ([Statistics Sweden, 2012](#)), an important part of the innovation process.

3.4.4 Knowledge, innovation and transformation

Adaptation requires the development, adoption and implementation of new knowledge and technologies. At its core is innovation and the need to transform our current institutions.

Although the solution phase of adaptation – especially implementation – has often been innovative in its nature and practice, it has primarily been framed using risk management and conventional change methodologies. This creates challenges for practitioners because risk frameworks only contain part of the methods needed to understand and implement actions. Innovation recognises that because outcomes are uncertain, ongoing processes, rather than final outcomes, need to be the main activity focus. Innovation processes contain established frameworks and processes that are needed for adaptation actions in the areas of:

- the introduction of new technologies – both social and technological;
- sociological aspects of change and transformation;
- management of uncertainty and the associated risks; and
- Iterative systems-based approaches.

Innovation

Innovation is the key to developing and applying solutions because it can place uncertainty in a context that is already understood and allows for an established methodology to be used.

Innovation is the development of new values and ways of doing things through solutions that meet emerging or existing needs ([Rogers, 2003](#)). This can be achieved through a number of different methods such as the development of new products, processes, services, technologies, or ideas, which are then taken up by markets, governments and society ([De Tarde, 1903](#)). The process of innovation can be incremental or abrupt and disruptive. Innovations can be social, economic or environmental.

Historically, these areas of innovation have been treated as separate and are often seen to have conflicting values. Until recently the costs and benefits of innovation have been recorded in primarily financial terms and have focused on social innovation inputs, without ‘counting’ social and environmental outputs or outcomes in a structured or systematic way ([Australian Innovation System, 2011](#)).

There are indications that this is changing. For example, the European Commission, United Nations and the OECD are currently developing a new economic growth accounting framework to incorporate social investments and environmental degradation into measurements of national prosperity ([Australian Innovation System, 2011](#)).

Innovation has been the key driver in the agricultural, industrial and knowledge revolutions. In each case, the adoption and implementation of new technologies has transformed how individuals, organisations and economies operate and think.

Innovation has three key stages:

- development;
- diffusion and adoption; and
- Implementation.

Central to innovation is the development, adoption and implementation of new knowledge and the frameworks that enable its use. [Rogers \(2003\)](#) defines diffusion as the process by which (1) an innovation (2) is communicated through certain channels (3) over time (4) among members of a social system.

At its core, innovation consists of knowledge and the people and institutions that generate and use it. Workers as generator of knowledge are seen as a valuable resource and a key component of the modern economy ([Drucker, 2011](#)) and end-user engagement is seen as pivotal ([Hippel, 1988](#)). This requires specific 'innovation systems' that enable collaborative development of knowledge and knowledge sharing networks across diverse sectors.

Innovation also considers the systems that it is applied to – an innovation system is considered as a framework for understanding and implementing innovation ([De Tarde, 1903](#)). It contains the interactions between the actors needed to achieve effective realisation and implementation of new ideas. Knowledge transfer, technology and communication are central to this.

How innovations are adopted and why they are adopted is key to being able to manage areas of innovation effectively. Adopters can be categorised into five categories: innovators, early adopters, early majority, late majority, and laggards ([Rogers, 2003](#)). The adoption innovation curve below shows how potential adopters perceive adoption over time and where critical mass is achieved.

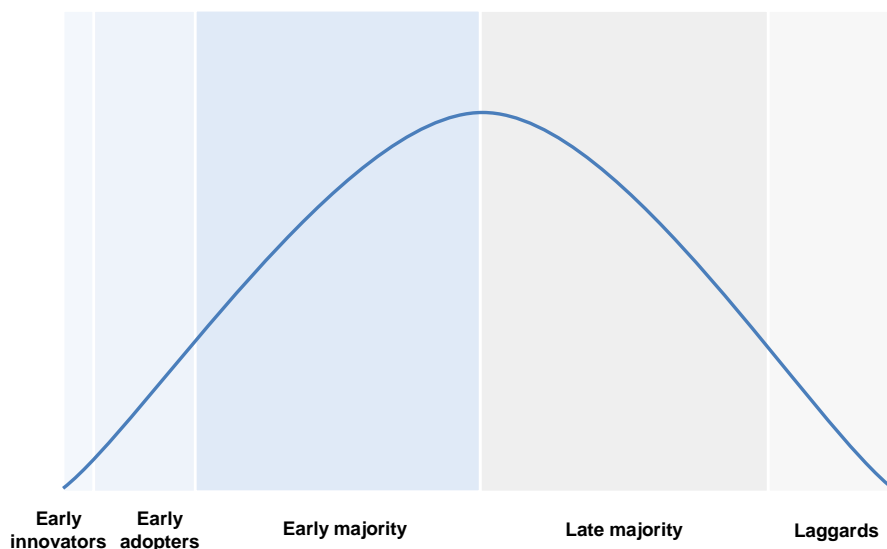


Figure 27. Adapted from adopter categorization on the basis of innovativeness ([Rogers, 2003](#)).

Five variables listed as key to determining the rate of adoption are ([Rogers, 2003](#)):

- perceived attributes of innovation;
- types of innovation decisions;
- communication channels (e.g., mass media or interpersonal);
- nature of the social system (e.g., modern or traditional norms, degree of communication integration); and
- Extent of the change agents' promotion efforts.

The decision to use an idea (adoption) is not the same as the use of an idea (implementation) ([Zaltman et al., 1973](#)). During the implementation stage, the innovation is often subject to change as it is adapted to specific end-user needs. Difficulties in implementing new ideas in organisations can either be seen as evidence that the new innovation either does not suit the organisation's perception of the problem, or that the problem is seen in terms of negative rather than positive outcomes ([Van de Ven and Rogers, 1988](#)).

To date, adaptation has largely been framed by the *problem phase* of risk management, where the main focus has been identifying specific climate risks and developing direct responses to those risks ([Van der Sluijs et al., 2003](#)). This tends to reinforce the status quo, as these responses are often applied to activities that are assumed not to be subject to change. It can also lead to disengagement, because the articulation of the solution is not based on action but rather further contemplation of the problem.

Aspects of innovation summarised above resonate with many core aspects of adaptation. Knowledge development and transfer, technology transfer and diffusion, and social learning are present in both bottom-up adaptation and innovation processes – all of which are essential for transformative action.

As [Dovers \(2009\)](#) points out, the initial capture by physical scientists of the adaptation process means that many methodologies have used concepts and language that are quite foreign to practitioners; this can be overcome by using appropriate pre-existing frameworks. As innovation practice is already established in operational and policy areas, it is already familiar and can assist with the integration of unfamiliar (new) knowledge and technologies. For example, although many in business and industry remain unfamiliar with the basic concept of adaptation ([Young and Jones, 2012](#)), they are familiar with some of the change processes embedded in social adaptation, business innovation and other change processes that can be used to implement adaptation actions. Innovation models can also help practitioners understand how to action the *solution phase* of the adaptation process and more effectively manage uncertainty and the associated risks.

The understanding of adaptation as a process with purpose and a mix of the old and new, with an evolving language feeding into a narrative of change, is a very useful construct for developing communities of practice around that technology. These communities are an essential part of enabling innovation.

Social technology

Social technology is an aspect of innovation and covers a group of “soft” technologies such as democracy and legal frameworks. Technologies have a stated purpose and combine practices with components ([Arthur, 2009](#)). Each technology has a specific language and grammar forming the narratives that guide its social application. The application of technology can also change the narrative informing technology leading to

further evolution of new technology (e.g., social media and Web 2.0). Technologies are hierarchical and are built from older technologies, with the innovation being supplied through a new purpose, recombination of older components, or with a new component added to older parts.

Adaptation to climate change is a relatively new social technology. It combines older technologies of social adaptation with specific innovations such as climate modelling, impact assessment and planning over intergenerational timescales. The narratives accompanying adaptation are both old and new, which is why adaptation appears both familiar and unfamiliar.

The reason for identifying adaptation as a technology is because of the role it plays between the generation of scientific knowledge and practical application of adaptation actions. Science researches the phenomena that feed into adaptation. In the case of climate change, the scientific narrative that comes from the climate research community has a large influence on how adaptation is framed and communicated.

Governance and policy

Governance and policy related to innovation can be complex because it needs to accommodate novel processes and unexpected outcomes over time. For example, the spread of new ideas can lead to socioeconomic gaps being widened due to uneven diffusion through society ([Rogers, 2003](#)). Research also needs to be integrated into the process.

Innovations can change as they move through the implementation stage by being adapted to specific end-user needs ([Rogers, 2003](#)). Policy and governance need to foster iterative processes to accommodate this and manage emerging risks that arise.

Core innovation needs are also consistent with those commonly identified for adaptive capacity (Figure 28). Innovation, like adaptation, is a social process that relies heavily on social capital because it requires the interaction and engagement of a number of diverse players to achieve end goals. Like adaptation, it is also uncertain and subject to change, requiring different frameworks and ways of thinking.

The application of innovation frameworks has great potential for the adaptation process – particularly in relation to implementation, capacity-building and communication, and knowledge transfer. Using an innovation lens is also potentially useful for policy-makers and organisations undertaking adaptation work, as it will help to better understand uncertainties surrounding operational aspects and to manage the risks associated with implementation. It will also assist with the understanding of the type of funding needed for aspects of adaptation and how it can be structured.

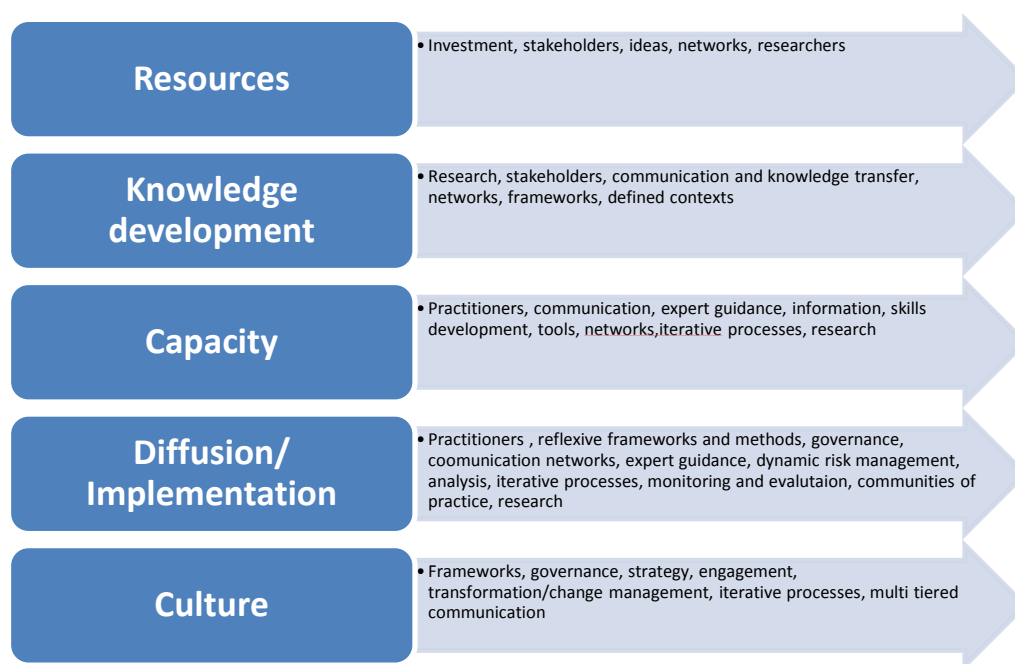


Figure 28. Key innovation needs (C. Young).

Knowledge and communication

How knowledge is developed and communication is undertaken has a direct impact on how effectively climate risks are understood, perceived, valued and responded to. Knowledge also needs to be seen in context of the systems it is used with, the institutions it is used in, and the people it is used by.

A key finding of the Beyond the Mean workshop (Section 3.2.2) was that climate change risk is often not valued because it is not understood. Communication was also seen as a core component of solutions by workshop participants. A key part of being able to effectively address this is an understanding of the roles that knowledge development and communication play.

Adaptation is a complex social process that is multi-tiered and involves multiple parties and knowledge from different sources. This knowledge needs to be applied practically in specific contexts. Communication in this field has three main purposes: to inform; to enable decisions; and to enable action ([Young, 2012](#)). Each purpose requires a range of communication tools and methods to be tailored to particular adaptation tasks.

Knowledge development and the communication enabling its implementation and use have been seen as separate functions that only interconnect when the process of knowledge development has been completed. In such circumstances, knowledge communication and transferral is seen as a bridge between separate functions as in Figure 29, which is a linear model of a systemic process.

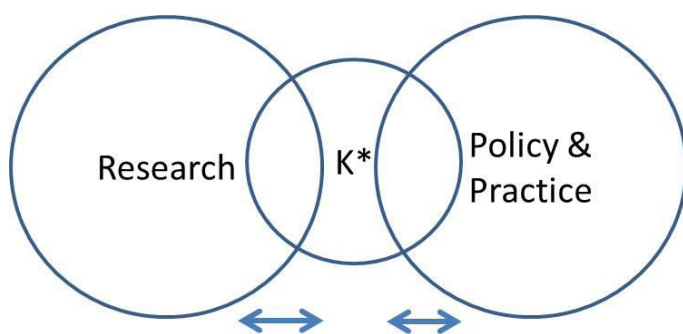


Figure 29. The linear technology-transfer view of how K* would link research to policy and practice ([Shaxson et al., 2012](#)).

Adaptation knowledge development cannot be effectively actioned if seen as a single transaction. Adaptation has a number of core knowledge functions that include: knowledge management; development; transfer; translation; brokering; exchange; and action ([Shaxson et al., 2012](#)).

Knowledge frameworks incorporating all aspects of knowledge from development to implementation have knowledge communication and transfer as a central component (see Figure 30). These types of frameworks are a pivotal part of building the capacity needed to enable transformation. Because of this, two-way communication with key actors needs to be part of the knowledge development from the onset of any activity.

There are two key aspects to the knowledge process. The first is the development of knowledge, and the second is the diffusion and implementation of this knowledge. To create ‘useable’ knowledge for adaptation requires a combination of both local and expert knowledge. To achieve this effectively requires a process of ‘deep collaboration’ with long-term, reflexive communication processes across a range of stakeholders. It also requires mechanisms that allow for the knowledge sharing and the translation of complex ideas and specific languages used by the different actors.

For example, the translation of aspects of scientific findings in relation to increases in temperature into visual maps that can be understood by social planners. This enables a common understanding to be achieved. These mechanisms also allow for two-way communication so that that the knowledge developed is ‘fit for purpose’ for the end-users as it has been informed by them.

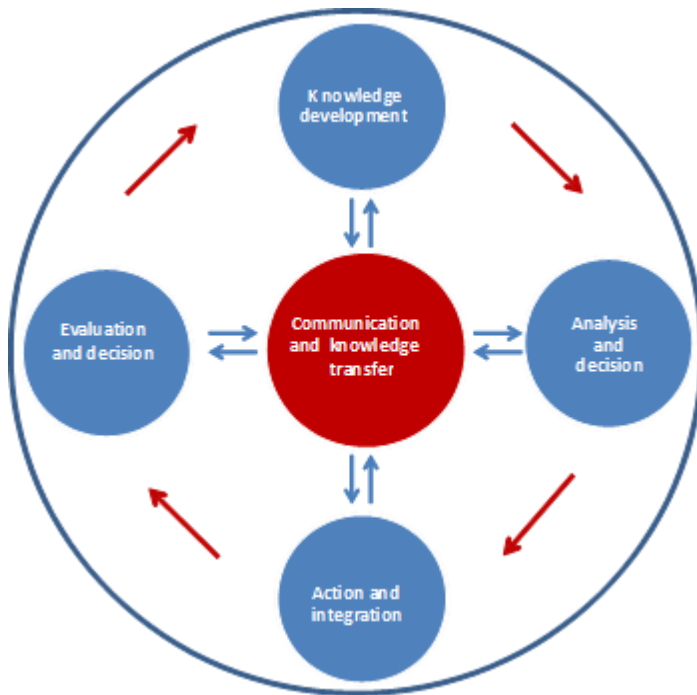


Figure 30. Adaptation knowledge framework (Young, 2013).

As much of the diffusion of adaptation knowledge requires new understandings, it has strong synergies with the innovation diffusion process outlined by [Rogers \(2003\)](#). This process works with the understanding that communication of new ideas is different to communication of established knowledge and is based upon the concept of *communication being a two-way process of convergence, rather than a one-way linear act in which individuals seek to transfer a message to one another in order to achieve certain effects* ([Rogers and Kincaid, 1981](#)).

The role of interpersonal communication is very much key to the adoption of a new idea ([Mahajan et al., 1990](#)) and remains a key aspect of how personal knowledge is obtained. This has implications for the communication of adaptation as it requires an understanding of the key phases of innovation and the social and technological aspects that inform the types of communication needed at different stages of the adaptation process.

Communication is also complex because of the nature of climate change and people's responses to this. Table 15 outlines common conflicts between the nature of climate change and common barriers encountered by practitioners.

Overcoming this conflict requires the use of tools such as collaborative narratives that allow groups of people to work through the conflict and develop common understandings around adaptation that enable decision-making and action.

There is also growing awareness that the 'conversations' being built around adaptation are different and require long-term time frames. This has ramifications for not only the process of how we develop practice, but also the need to transform current institutions and rebuild communities to enable this.

Table 15. Comparison of climate change attributes with widely held preferences for the types of decision-making people prefer (Young, 2012).

What climate change is	What most people want
Complex	Simplicity
An evolving field and cannot be solely based upon historical evidence	Things they know and have experience of
Innovative - not every solution will work	Solutions that work
Time consuming to address effectively	Quick fixes
Difficult	Things to be easy
Uncertain	Security
Requires large scale social change	Things to stay the same
Questions	Answers

The role of research

Research and research institutions have a key role in adaptation in the development and provision of expert information, evaluation and monitoring of adaptation actions and assisting practitioners and policy-makers with understanding and decision-making.

Currently the role of research institutions in adaptation is widely-acknowledged but poorly understood. Research needs to be embedded in the adaptation process serving a variety of purposes that are task-specific (Table 16).

Table 16. Summary of task-oriented needs for research.

Task	Key aim	Research required	purpose
Identification of the problem	To create understanding of what the problem is and how it works.	Climate sciences, economic, social, environmental, political.	To assist with the collation, analysis and valuation of climate impacts. Development and provision of knowledge and information to enable better understanding of the problem. Development of research communication that is fit for purpose
Assessment and decision-making	To assist with assessing what risks should be actioned and how they should be actioned.	Climate sciences, economic, social, environmental, political.	To provide support in the form of guidance regarding analysis of options required by decision-makers. Development of research communication that is fit for purpose.
Implementation	To monitor and evaluate actions and support analysis and decision making	Climate sciences, economic, social, environmental, political.	To monitor and evaluate adaptation implementation and provide comment and guidance to assist decision making during this process. Development of research communication that is fit for purpose.

Adaptation and innovation research are highly synergistic. At the institutional scale – to manage multiple and competing values in a research environment – adaptation research needs to be transdisciplinary. Because this research needs to be applied practically, it also requires mechanisms for collaboration and knowledge sharing between research bodies and stakeholders, which is a key part of the transdisciplinary research process ([Welp et al., 2006](#)).

Although research aims to deliver information for policy formulation and other forms of decision-making, the current ability of researchers and research institutes to achieve this aim is inconsistent. Much of this has to do with the way research is being developed and communicated. Science communication and knowledge transfer and application both need to be strengthened in order to manage the risks associated with rapid changes in climate. The role of boundary organisations to assist in this translation also needs to be supported, and should be developed in collaboration with stakeholders to identify where this strengthening should occur.

3.4.5 Transformation

The impact of a 2 degree or more temperature rise on the earth's systems would change the environments we live in ways that we have yet to experience. We will have to change how we think about these environments and the way we live in them. Transformative actions that combine key aspects of innovation and adaptive management are needed to ensure future sustainability.

Currently many of the systems that we operate under, such as our legal systems, are based upon the assumption that the ecological systems they rely on will remain stable; therefore, the overriding aim is to preserve this status ([Craig, 2010](#)). Under gradual change, the assumption is that we can maintain this status by ‘nudging’ conditions back to normal. Step-like climate change is likely to increase instability resulting in unpredictable non-linear changes within our social and environmental systems, the outcomes of which we may have little ability to predict or control (Section 3.1.3). This leads to a pressing need to transform systems that we currently manage based on the assumption of stationarity and gradual change.

([IPCC, 2012b](#)) define transformation as:

“The altering of fundamental attributes of a system (including value systems; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biological systems)”.

Transformation is the point at which these changes occur within or to a system. Transformation can be spontaneous or by default and the result of a trigger such as an extreme event, as in the case of the town of Grantham in the Lockyer Valley (see Box 1).

It can also be planned through a deliberative process as is often the case in industry with a specific transformation goal in mind which is enabled by transformative processes. In 2007, for example, Siemens, one of the world’s leading manufacturing and engineering companies, launched a transformation program called “Integrate, Enable, Collaborate” that was driven by the introduction of a PLM – a single platform for all processes involved in designing, building and developing multiple products. The strategic goal of the program was to transform their business practice to “halve the time to market” ([Atos, 2012](#)).

Box 1: Lockyer Valley region – Voluntary relocation case study

In January 2011, floods devastated Grantham in the Lockyer Valley region in Queensland, home to approximately 360 people. The flash flooding resulted in unprecedented levels of property damage and destroyed more than 130 homes (Lockyer Valley Regional Council, 2011). The council, in close collaboration with the community, decided that due to the profound effects of this event they would take a proactive stance when rebuilding their community by developing a planned voluntary relocation scheme.

935 acres of land was purchased by the council adjacent to Grantham that was above the flood lines reached in January. This was to ensure that residents could rebuild in a safer environment. The council also committed to invest \$30–\$40 million over the coming year to support development. Lockyer Valley council worked with the community to develop the master plan for the new community through the *Strengthening Grantham* Community Workshops. This final plan included a community centre, show grounds and a possible new school.

The Lockyer Valley Regional Council Community Recovery Plan (23 February 2013) and the Grantham Relocation Policy (11 May 2011) were developed and a flood study of the region was undertaken.

The first release of land was in June 2011 when 80 parcels of land were made available to the owners who had been most impacted by the flood. (This was later extended to 90 due to the uptake of the scheme.) These parcels were offered as exchanges of ‘like for like’ parcels of land and owners incurred no cost. They were then allocated to the residents through a ballot system.

Although current literature highlights the need for transformation and some research has been undertaken by sectors such as agriculture, [Rickards and Howden \(2012\)](#), further research is needed to understand more fully what sort of system changes are likely and how they will impact in different sectors. Transformation is not predictable in nature, and seeking to control the process of transformation through rigid structures is unlikely to be successful. As a result, transformation requires guiding processes that enable and contain a number of different elements such as iterative systems, collaboration, leadership and continuous learning ([O'Brien, 2012](#)).

Assessing transformation

Very little is known about the costs and benefits of transformation, which makes it difficult to quantify. Transformation is non-marginal and is required when marginal change is not cost-effective or is technically impossible ([Hallegatte et al., 2011](#)).

Costs are often presumed to be very high ([IPCC, 2012a](#)) requiring large initial investment with benefits not realised for many years. Because transformation is context-specific and has geographical, institutional and temporal aspects that encompass both tangible and intangible costs, it requires a combination of economic methods for effective assessment. As a result, costs are often under-estimated ([World Bank, 2010](#)) – in particular ‘soft costs’ and ongoing costs that will persist for years to come. There is a need to understand more fully how to assess these costs.

A key recommendation of the [World Bank \(2010\)](#) to avoid the (often intangible) costs of community disintegration and anxiety/anger over the relocation is to ensure that there is meaningful community engagement as part of the process. This type of community engagement is challenging because it may be seen as time-consuming, constraining and costly. However, numerous studies in the disaster field have highlighted the importance of community engagement as a key factor in the success of transformation processes such as relocation of communities (e.g., [Perry and Lindell, 1997](#)).

Institutional values can direct decision-making in transformation. For example, a profit-making company might be interested solely in economic sustainability. How and what they choose to transform will be different to a company who have social and environmental sustainability as a core part of their value system. Communities who choose to transform may focus on the core value of the community, such as social cohesion or community resilience, and this will determine the nature of the transformation and the priorities.

This is an emerging area that will develop. However, there are a number of economic tools that are currently available that can assist this process (see Section 3.4.3).

The role of policy

This report has highlighted several salient issues for climate change adaptation policy and the decision-making approaches that inform it. We have shown that:

- The dominant presentation of the climate science leads to an assumption of gradualism that is highly contestable. A stepped trajectory is more likely to occur.
- The current economic, policy and institutional models are not equipped to deal with non-marginal changes.

These points indicate a need for a re-thinking of economic, policy and institutional models if they are to facilitate the transformation of social, environmental and economic systems required for adaptation.

Policy may foster transformation incidentally by altering system interactions, or purposefully in order to achieve a desired outcome. The complexities of the interactions governing our social, ecological and economic systems are well-established. The potential for transformation, either by default or design, is important for adaptation planning to consider because of the long-term impact of policy decisions. The transformation literature shows – both in response to climate events and more generally – that if transformation is to be a deliberative process, it needs to be actor-driven and innovative in order to succeed.

Institutionally, this is challenging because many institutions are top-down, using linear frameworks within siloed organisational environments. Cross-sectoral and whole-of-organisation models are required. Current policies also tend to operate on short to medium-term time frames, are reactive in their nature and can be subject to political expediency, which acts as a barrier for transformation.

Land use change, either gradually via regulated planning or abruptly by relocation, also offers both challenges and opportunities. Land use planning via regulation systems is frequently cited as a key site for both hazard mitigation and climate change adaptation (e.g., Productivity Commission, 2012). Despite the potential of the planning system, even in developed countries with strong institutions, an enduring theme in disasters research is the staunch obstacles to utilising it for disaster risk reduction. [Travis \(2010\)](#) cites legal and social opposition to land use regulation in high-risk areas in response to

powerful economic pressures which highlights the need for clear leadership in this area.

Transformation is important as a concept and a strategy because it offers an approach to adaptation specifically for step or non-linear change. It allows institutions, sectors, communities and people to adjust to new circumstances or prepare for anticipated major change. This is in contrast to more normative approaches that are, at best, incremental or resistant to change.

3.4.6 Maladaptation

Because adaptation is uncertain in its nature and its interactions cover multiple systems, domain, timeframes, processes and actors, the risk of maladaptation is high. Managing these risks to avoid increased vulnerability is a key task for all actors in the adaptation field.

The [IPCC \(2012b\)](#) defines maladaptation as:

“Any changes in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability but increases it instead.”

Maladaptation has been identified as a serious threat to the success of climate change adaptation initiatives ([Hallegatte et al., 2011](#)).

[Barnett and O'Neill \(2010\)](#) identify five types of maladaptation. They state that actions, relative to alternatives, are maladaptive if they:

- increase emissions of greenhouse gases;
- disproportionately burden the most vulnerable;
- have high opportunity costs;
- reduce incentives to adapt; and
- set paths that limit the choices available to future generations.

As [Jotzo \(2010\)](#) points out, it is highly likely that it is the threat of these low probability catastrophes that is driving concern about climate change in the first place. In section 1.2.3 we outline how the application of orthodox economic approaches to situations with uncertain catastrophic risk may be a source of maladaptation.

The issue of low probability/high-impact events has been flagged in the climate change adaptation economics literature as having significant potential to skew the entire direction of adaptation action. [Travis \(2010\)](#) contends that the literature on climate change adaptation focuses on gradual change that there is a lack of attention to extremes and rapid climate change. Climate change seen only through this lens can increase maladaptive responses and vulnerability.

Options highlighted by the disasters field to reduce maladaptation include giving high priority to low-regrets adaptations ([Hallegatte et al., 2011](#); [IPCC, 2012b](#)) because they are seen as ‘adaptive’ in all situations. In the context of rapid changes, such measures may no longer qualify if they do not cope with the rapidity of change. This highlights the need for measures that are iterative and respond to new information as it becomes available ([Hallegatte et al., 2011](#)).

Merz et al.’s ([2009](#)) example of flood mitigation via levees in Germany shows that when traditional and analytically convenient models do not consider the indirect and

intangible costs of catastrophic events and/or assume risk neutrality, they under-prepare for extremes (Box 2).

Box 2. Levee Effect

The levee effect occurs when extra development occurs behind a flood protection levee; thereby increasing potential future damages (see also Travis, 2010). Unfortunately, levees often fail; in 1982 the National Research Council found that levee failures were responsible for approximately a third of flood disasters in the USA ([Freudenberg et al., 2009](#)). In building behind the levee and not taking further protection, people are assuming that they have adequate protection against all floods. In fact, levees are only designed to protect against flooding up to a certain point, say a 1/100 year event. Finally, there is evidence that levees actually increase flood levels by altering regional hydrology, reducing natural flood mitigating features and shifting flood risk downstream ([Freudenberg et al., 2009](#)).

The levee effect highlights how maladaptation may play out under orthodox climate change adaptation economics. Adaptation decision-makers must consider the complex reactions different groups may have to adaptation initiatives – they may be maladaptive if they result in high opportunity costs and reduce incentives to adapt (Barnett and O'Neill, 2010; Travis, 2010). The IPCC (2012b) highlights the importance of considering the spatial and temporal dynamic of exposure and vulnerability when assessing adaptation measures. This is supported by the levee effect which is maladaptive in if it either increases the penalty of failure or limits the choices available to future generations (Barnett and O'Neill, 2010).

Without the transformation of current institutional models, the risk of maladaptation is significant. It is possible for policy to facilitate catastrophe as seen in the example of Hurricane Katrina and the flooding of New Orleans. [Burby \(2006\)](#) states:

"In summary, federal policies have sought to make areas at risk from natural hazards safe places for urban development by reducing the degree of hazard and by shielding hazard-area occupants from financial risks of loss. Over time, these policies have facilitated the development of these areas, as illustrated by urban growth in New Orleans, but they have increased the potential for catastrophic losses in large disasters. In this sense, Hurricane Katrina and the flooding of New Orleans could be viewed as an expected consequence of federal policy rather than an aberration that is unlikely to be repeated."

This assessment of long-term disaster risk reduction planning resulting in catastrophic maladaptation provides a lesson for climate change adaptation and highlights the need for a consideration of how factors such as risk, complex interactions between systems and the values they engender, can compound. The potential for possible maladaptation needs to be identified in advance and reviewed regularly. The use of scenario planning can be useful in this process.

The experience of the disasters field has key lessons for climate change adaptation economics in relation to avoiding maladaptation:

- Catastrophic impacts ought to be given more weight in decision-making. Catastrophes have wider intangible and indirect costs to which the community is strongly averse.

- The phenomena of the levee effect demonstrates that complex social reactions be considered in planning adaptation. This is essential even though it requires more complex economic modelling and analytical rigour.
- The dynamic interaction between disaster risk reduction and socioeconomic development shows that outcomes are improved when due consideration is given to both areas. Equity and vulnerability also needs to be balanced with economic analyses.
- Decisions have the potential to be maladaptive if they increase vulnerability and/or neglect to consider the impact on all stakeholders, requiring comprehensive engagement with stakeholders in decision-making.

The role of economics in maladaptation

The levee effect is an example of a broader issue of perverse incentives when a 'rational' response to an adaptation increases vulnerability. Uncertainty and/or the possibility of irreversible catastrophic damages mean that alternatives to the standard CBA framework, such as those discussed in Section 3.4.3 become valuable.

Research with regard to risk perception and averseness indicates that people have little or no control over disasters; they are risk averse (which is in contrast the standard CBA approach, which is risk neutral). More generally, CBA assessment of flood levels tend to only return a positive result for very low levels of protection (for example up to a 1/10 year event), whereas the social standard is often a lot higher (a 1/100 year event). These non-linear explosions of costs at the level of catastrophe are not captured within the CBA framework. Furthermore, it is often the case that decisions are made politically before any formal costing takes place. On the other hand, people who have control over how a risk plays out are much more tolerant, suggesting that 'soft' options for risk management may promote risk tolerance and increase community resilience.

These points make a strong argument for a revision of the current theory to better reflect practice and society's expectations. This approach might see society identify the level and type of risk that is tolerable and then identify, via CBA, the optimal way of achieving this level of risk. This approach has the dual benefit of circumventing the problem of assumed risk neutrality in CBA, and providing a formal and transparent framework for what is a nebulous process.

3.4.7 Developing capacity

Adaptation is a relatively new field. In the context of rapid change, several areas of capacity need to be developed by institutions, particularly in relation to understanding and valuing the resulting risks. Innovative frameworks, mechanisms that allow for the development of new skills and understandings and the resources to support them are needed to enable this.

Adaptive capacity is defined by the IPCC as '*the ability of a system (region or community) to cope and thrive in the face of change*' ([IPCC, 2007b](#)) and is closely linked to resilience as the ability to buffer change, learn and develop ([Folke et al., 2002](#)). It is closely linked at the institutional scale with governance and is needed to be able to effectively address rapid change by identifying the problems and action the solutions needed to enhance the ability of institutions to recover from disturbance and facilitate transformation ([Preston and Stafford-Smith, 2009](#)).

Increased decision support, R&D, data and information to support adaptation and policies to reduce vulnerability are all aspects that increase adaptive capacity.

Capacity-building may be needed due to increasing economic vulnerability exacerbated by climatic stress, as is occurring in regions of Australia that experienced the millennium drought followed by fire and heat stress, then flooding. [Nelson et al. \(2010\)](#) propose five types of capital for consideration in relation to adaptive capacity: natural; manufactured; social; human; and financial. These provide the resources for developing capacity, but the real impact of capacity is in the processes that enable it to be used.

Of special interest is institutional capacity, which can be summarised under the following three topic areas ([Urban Capacity Building Network, n.d.](#)):

- **Human resource development** – the process of equipping individuals with the understanding, skills and access to information, knowledge and training that enables them to perform effectively.
- **Organisational development** – the elaboration of management structures, processes and procedures, not only within organisations but also the management of relationships between the different organizations and sectors (public, private and community).
- **Institutional and legal framework development** – making legal and regulatory changes to enable organisations, institutions and agencies at all levels and in all sectors to enhance their capacities

Current institutional frameworks rely upon siloed operational structures that project the future from the past. As rapid changes will result in risks that exceed those of past experience, the capacity to plan effectively requires institutional frameworks that can make decisions in advance rather than relying on post-event responses to fulfil their KPIs. They also require collaborative rather than competitive mechanisms; for example, the development of collaborative narratives for sustainability and change that can be shared between institutions.

A lack of understanding about the risk of rapid change leads to those risks being undervalued, which affects the level of preparedness and response. Knowledge transfer and communication are key to enabling this. Communication sources across different levels of government and boundary organisations need to be mapped so that information can be disseminated effectively (Young, 2012b).

The development of tools and supportive frameworks that are ‘fit for purpose’ and create better understanding of the problems faced and the solutions pathways, assist decision-making and are an important part of the capacity-building process ([Webb and Beh, 2013](#)).

Factors that enable institutional adaptive capacity include ([Preston and Stafford-Smith, 2009](#); [Shaxson et al., 2012](#); [Webb and Beh, 2013](#)):

- resource availability – financial, technological, human;
- communication, knowledge development and transfer systems;
- governance;
- innovation and transformation of current intuitional frameworks and processes; and
- development of specific products – tools, methods and processes; e.g., programs for innovative adaptation, and monitoring and evaluation tools.

These are elaborated on in Table 17.

Table 17. Summary of capacities needed to deal with rapid changes in climate extremes.

Core Capacities	Rationale
Risk management	Greater understanding of the impacts of rapid changes and the risks they pose. Valuation of risks and the identification of ownership at the institutional scale. This includes the need to review and develop economic tools and methods that are fit for purpose
Collaborative capacity	Development of effective working relationships between stakeholders to enable effective decision-making and implementation.
Transformation/Change Management	Current institutional systems are not designed to effectively deal with the onset of rapid changes due to their siloed and competitive nature. These systems need to develop an innovative culture that is comfortable with managing transitional processes.
Monitoring and evaluation	Methods for monitoring and evaluating adaptation are a key part of the innovation process. Iterative methods ensure that new learning is captured, especially from unexpected outcomes. Multiple values across different time frames need to be included.
Knowledge development	Knowledge derived from research needs to be developed in such a way that it addresses the problem-solution space and is not framed the way that researchers see the problem. Collaboration with end users is required to ensure that knowledge developed is useable and fit for purpose.
Knowledge transfer and communication	Knowledge transfer and communication will transmit, adapt, adopt and implement new and evolving ideas. Narratives and creative processes need to become much more prominent in preference to toolkits and traditional decision support systems.
Policy development	New policy mechanisms that enable an 'all agency' approach to proactive, iterative and non-competitive policy-making. Positive incentive-funding models can support innovative policy initiatives.
Innovation theory and practice	Innovation theory and practice will help provide thinking frameworks and tools for operational aspects of implementation.
Process and systems development and integration	Adaptive processes can become part of everyday business. The integration of adaptation options into operational systems and processes will ensure a whole-of-organisation approach is adopted.
Decision-making under uncertainty	Skills development, especially how to make decisions under uncertainty, would benefit from a better knowledge of the innovation process. New frameworks, tools and systems of monitoring can enable this.
Strategic capacity Visualisation	Strategic capacity and visualisation are key elements for planning and important elements for developing proactive policy and activities.

Private industry and civil society

Private industry and civil society have a limited understanding of conventionally framed adaptation. Building the necessary understanding that enables clear decision-making in relation to planning and response to rapid change is pivotal. Knowledge and information that is sector and context specific is a key requirement to support efficient markets under rapid change (Table 18). Accessibility to relevant information about climate change and adaptation is important especially for private adaptation by individuals and small and medium enterprises. Investment is also needed to support markets for adaptation goods and services. Peak organisations have a pivotal role in assisting this.

Table 18. Industry sector specific adaptation requirements

Sector	Needs in relation to rapid change
Logistics and Supply chains	Plan for disruption regional to international levels. An understanding of how these disruptions may occur and the threats and opportunities this offers for businesses.
Building industry	Change has to be well planned and incremental. Education of organisations and consumers; e.g., consumers are more concerned with fittings than the structural integrity of dwellings, and with capital costs compared to running costs. Promotion of fit for climate housing needs. Changes in practice are driven by regulation, requiring fast-tracking of appropriate standards. Ongoing skills development in relation to best practice in relation to climate-resilient buildings.
Parks	Extreme weather events impact on parks organisations and management – and have been apparent for the last 20 years. Post event response is becoming more expensive, and the human cost is also increasing. Need standards for consistent monitoring and costing in addition to tools that can assess the full value of parks.
Small to medium businesses	This sector is financially vulnerable, as it is hard for many businesses to plan long-term. They need information that is accessible and relevant. Many small businesses are not always connected into networks, so communication is an issue.
Tourism	80% SME and micro businesses, very vulnerable to climate shocks Improved communication is needed.
Health	Evidence-based tangible activities and strategies are needed. Capacity building in relation to responses to climate change and also greater understanding of organisational aspects of climate risk.
Agriculture	Agriculture is already adapting because it has to, but farmers are financially vulnerable to cascading climate events. Need for policy that addresses economic and social and environmental aspects in an integrated way.

Sector	Needs in relation to rapid change
Finance	<p>Expansion of financing tools and mechanisms to increase the level of social and environmental investments through bonds and other investment funds.</p> <p>The industry needs to explore how it can assist long-term financial planning and increase collaboration with the sectors they service. Collaboration within the finance sector can address how to maintain economic stability by preparing for rapid change. Higher risk due to rapid change will require higher levels of investment at all levels from infrastructure through to social investments.</p> <p>Greater policy surety is needed to allow proper planning of future investments.</p>
Insurance	<p>Possible need for a new regulatory structure that is more resilient to rapid and large increases in payouts that may exceed premiums. Consideration of how reinsurance will be affected by cascading events, and how it can promote future economic stability through the development of new products.</p>
Emergency Sector	<p>Different modes of communication that engage more effectively with vulnerable aspects of the community, such as the CALD sector. Encouragement of pro-active responses in the sector and communities.</p>
Manufacturing	<p>Vulnerable to supply chain disruption, resources restrictions and physical risks to employees. Fit for purpose information can create a better understanding of adaptation and the opportunities and risks associated with it.</p>
Community Sector	<p>CSOs are highly vulnerable and poorly prepared to respond to climate change and extreme weather impacts. There is a need for inclusion into policy and research settings where the impacts of climate change are more fully supported.</p>

Financial arrangements

Financial arrangements, particularly for areas such as infrastructure, need to be long-term and not constrained by election cycles:

- Funding need to address both soft and hard infrastructure requirements rather than create siloed funding, which may result in maladaptation.
- Conventions such as drip-feed funding can work if they are guaranteed over the long-term. This enables bodies that access these funds to invest in long-term strategies using shorter-term investment cycles.
- Reimbursement models, such as the one used by Austrade, where a percentage of expenditure on specific tasks are returned after the actions have been implemented. This is particularly useful for stimulating early innovation in the private sector.

Three key areas for funding infrastructure that are relevant for both hard and soft infrastructure are:

- the development of new infrastructure;
- the maintenance of existing structures; and
- the upgrading of existing infrastructure to meet a new need.

Governance

The development of appropriate governance is required for both adaptation policy and for supporting adaptive capacity to ensure that risks are adequately managed.

At a national level, coordination by COAG is needed to determine the best vertical and horizontal structure that addresses:

- the propagation of risk through the governance system involving government, the judiciary and civil society; and
- the institutional arrangements required to manage the risks of rapid change via adaptation.

The institutional arrangements would require a large-scale effort under COAG similar in scale to the development of the mitigation agenda. It would also include research and development to be more integrated into the adaptation process. Monitoring of implementation at the local and regional level would help collate lessons, identify areas of innovation and transfer capacity and governance arrangements that work. An assessment of current assurance systems and tools used by industry and their applicability for monitoring and evaluation aspects of adaptation activity would also be useful ([Webb and Beh, 2013](#)).

Governance in relation to adaptation at state government level is evolving; areas that are currently being developed are:

- development of multi-portfolio projects;
- monitoring and evaluation;
- knowledge development and communication;
- planning and responses in relation to effective management of extreme events and their impacts; and
- collaborative partnership frameworks

In relation to rapid change, governance frameworks need to effectively plan for propagating risks across domains and to manage the potential impacts of thresholds being exceeded in different sectors or systems. These will also need to be understood in terms of tangible and intangible costs that include fiscal, social and environmental currencies.

Developing governance is a major challenge at local government level because actions at this level revolve around implementation and communication, especially with local communities and businesses. There is still a lack of clarity in key areas such as:

- areas of roles and responsibility;
- monitoring and evaluation;
- understanding of appropriate governance systems;
- legal responsibilities in relation to planning and public liability; and
- ascertaining tangible and intangible values across multiple time frames

Lessons for governance and the development of adaptive capacity can be gained from the failure of water policy and governance to achieve sustainable integrated catchment management (Table 19).

Table 19. Catchment Management Organisations (CMO) Governance Criteria
([Roberts et al., 2011](#))

Governance criteria	Analysis of criteria	Performance
Clear institutional objectives	Currently CMOs have strong statutory powers in Victoria and South Australia (1), limited ones in NSW, and no statutory powers in Queensland and ACT	Low
Transparency	CMOs have low access to scientific data; have problems handling complex information; focus on outputs rather than outcomes; and find it difficult to report meaningfully	Commonly low
Accountability	Upward accountability processes (reporting on budgets, activities, outputs) are well established, however need streamlining of reporting	High
Interconnection – formal and informal institutions	All stakeholders are not equally represented in CMO decision-making. While governments and primary producers are well represented, urban residents and indigenous communities are not	Moderate
Adaptiveness	The different institutional structures operating in the Basin states for CMOs suggest that their adaptive capacity is at least moderate.	Moderate
Appropriateness of scale	CMOs are well suited to manage natural resources at a regional / catchment scale, but find it difficult to plan for cross-boundary issues and maintain hydrological connectedness at larger scales	Moderate
Integration	Capacity of CMOs for vertical and horizontal integration is “weak to moderate” and cross-regional integration is a challenge. CMOs generally do not use formal decision frameworks to integrate different types of information	Moderate between agencies Low for data integration
Capability	Capability varies greatly depending on size, resources and maturity, having implications for establishment of effective systems. Most CMOs do not have sufficient resources and have difficulties in attracting and retaining staff	Highly variable, ranges from low to high

3.4.8 Policy implications of rapid change

The policy implications for responding to rapid changes in climate-related risks are substantial. COAG has already stated that a national, coordinated and cooperative effort is needed to enhance Australia’s capacity to withstand and recover from emergencies and disasters ([COAG, 2011a](#)). As these disasters are likely to increase both in severity and frequency with rapid change identifying the solutions to reduce the risk are pivotal.

The knowledge that extremes can change much more rapidly than estimated by the latest climate projections suggests that a proportionate policy response is needed. As mentioned in Section 3.3.4, even though recent policies dealing with emergency management and disasters apply the language of resilience and advocate breaking down institutional silos and community engagement, the institutional structures that

support policy-making and application still contain implicit assumptions that fail to recognise the need for transformation ([Folke et al., 2002](#)). Instead, they are linear, work on prediction and control and treat human and natural systems as independent.

Recent examples of the recognised need to change:

“... the emergency services agencies in Victoria operate in a siloed structure with each agency focused on legislated obligations to address specific hazards.”
([Comrie, 2011](#)).

“A resilience approach to managing the risks to critical infrastructure encourages organisations to develop more organic capacity to deal with rapid-onset shock. This is in preference to the more traditional approach of developing plans to deal with a finite set of scenarios”.([Australian Government, 2010a](#))

The mismatch between intentions and actions may be in part due to the lack of understanding as to how to actually transform across diverse institutional sectors. Other barriers may include the size of the investment of time and resources needed to enable transformation to be achieved.

Transformation at the institutional scale needs to be supported by a proactive policy environment. All relevant decision-makers *need to see all hazard risk mitigation and response as part of their role, and be empowered to carry it out...* ([Australian Government, 2010a, p 13](#)). As recent investments in policies for disaster are currently reactive and more focused on disaster recovery rather than disaster risk reduction by a ratio of greater than 50 to 1 ([Productivity Commission, 2012](#)), it is clear that this imbalance will need to be addressed to reduce considerable futures losses.

Increased levels of climate risk in future may lead to lower standards of protection, but this proposition needs to be accepted as part of a broader social contract. Increased levels of community resilience could counteract this trend. Social acceptance, if it were to occur, would be helped by risk ownership becoming better acknowledged at the institutional scale. This includes the sharing of public and private risk, individual risk and that associated with the commons, an area dominated by natural assets and infrastructure.

Whether a given activity or location can thrive depends on the balance between market-driven adjustments to mean climate shifts that remain within the coping range of climate and extremes that exceed subcritical or critical thresholds. Rapid changes will tip this balance much faster than anticipated. Changes above a critical threshold – particularly one that crosses domains – will cause significant distress in a system if unprepared for. However, for the bulk of climate variation below critical levels, existing adaptation analogues are likely to be available. Markets will generally manage such changes readily but may need increased information to do so.

Figure 31 shows an idealised distribution of temperature frequency, with thresholds denoting extreme hot and cold. If distribution shifts rapidly to warmer conditions as in the lower chart, then extreme heat thresholds will be exceeded at an unprecedented rate.

This model suggests that managing extremes requires a considerable policy response, whereas managing changes around the mean can be largely managed by market forces as described above. Rapid changes will tip the balance more to policy responses, suggesting that such changes may need stronger industry-government dialogue in order to better understand which changes are manageable and which require increased cooperation in order to balance market-driven and policy-driven adaptations.

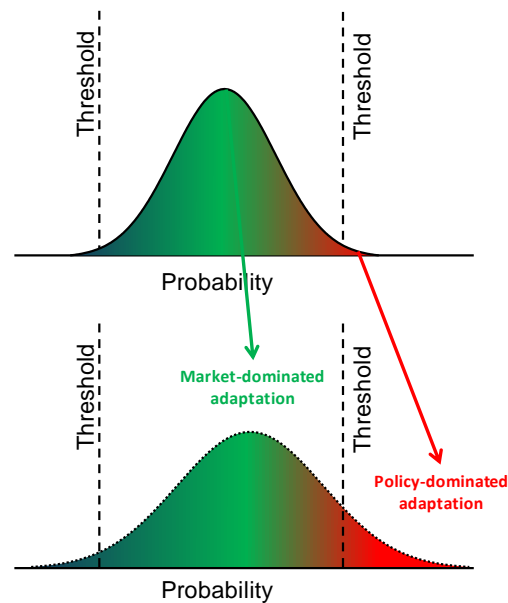


Figure 31. Schematic of temperature frequency about the mean showing a shift to warmer conditions with a greatly increased exceedance of extreme heat events.

This has ramifications for both public and private sectors and highlights the need to define more clearly who is responsible, how they are responsible and what mechanisms are needed to ensure resilience is developed effectively. It also points to the importance of better understanding the relationship between public and private sectors in relation to these events.

Table 20 summarises risks, risk propagation and potential adaptation policy for the major adaptation clusters. Climate risks at the local, sectoral and regional scale can be managed by local government, regional and catchment bodies, sectoral and state-based strategies. As mentioned earlier, climate variability falling within the standard coping range can largely be managed through local plans and market-based strategies supported by policy that fosters innovation, provides appropriate standards and protects the vulnerable. The exception is when mean climate approaches a critical threshold and the activity or location is at risk of becoming unviable.

Table 20. Summary for each of the five adaptation clusters detailing risk, risk propagation and major types of adaptation policy for each (examples need further development).

Services				
Scale	Local	District/Region	State/National	Global
Impacts	Small events at local scale	Regional events or accrued local stresses	Large events and accrued regional stresses	Global load of shocks
Risks	Insured and uninsured losses of property and incomes, loss of stock and trade, possible injury or death	Lost income, possible community stress, local government services, damage to LG infrastructure, reduced natural resources, local businesses affected, local supplies disrupted	Current accounts affected, government as insurer of last resort, large insurance payouts, supply chains disrupted	Global insurance burden, food and oil prices, trade exposure, economic climate, availability of finance
Risk propagation	Risks pass from commons to local systems affecting production and wellbeing	Losses accrue from local areas	Government as insurer of last resort, industry viability affected by regional and global influences (e.g., insurance, finance)	Reinsurance, loss of governance, environmental refugees
Adaptation policies	Local knowledge, information transfer, community exchange, local volunteers groups, health groups, small business	Local government plans, regional, development/adaptation plans, CMA-scale planning, regional infrastructure, emergency services (SES, CFA)	State and federal government policies, peak industry bodies, professional bodies, large business and industry	Adaptation funds, international policy

Goods				
Scale	Local	District/Region	State/National	Global
Impacts	Changes to resources (soil, water, temperature), events causing loss of production	Catchment-scale (inland) or coastal region resource effects and events, some downstream effects on secondary businesses	Large production areas affected, flowing into other major industries	International prices, trade impacts
Risks	Risks to local viability, environmental and economic, employment	Risks to regional viability, loss of income and employment, flow-on effects	Major industry/resource reform may be needed, regional adjustment schemes, could affect essential services	Differential effects on commodity and manufactures, and input costs, international trade, food security
Risk propagation		Local viability aggregated at regional level	Major conflict between changing resources, social capacity and environment likely	Place of resource within globalised economy
Adaptation policies	Maximise production, diversify or switch	Industry and regional development policies, securing underpinning resources	National policies at industry and sector scale, transfer of capacity to regional scale, R&D	Trade policy, international treaties, aid and development assistance

Capital Assets and Infrastructure				
Scale	Local	District/Region	State/National	Global
Impacts	Extreme events, changed exposure to chronic events	Regional events, accrual of local maintenance loads	Large events and accrued regional stresses	Global load of shocks
Risks	Increased maintenance, rebuilding, retrofit, higher establishment costs	Repair/rebuild after extreme events	Retrofit and new infrastructure requiring state and national government investment	International cost of finance, global engineering pool (skills)
Risk transfer	Inability to source local infrastructure transferred from larger scale	Under-adaptation and maladaptation increases exposure of current infrastructure	Under-adaptation and maladaptation increases exposure of current infrastructure	Nations under-adapt risking regional and global security
Adaptation policies	Insurance, planning better manages risk and responsibility, better education of risk to individuals and small orgs	Quality control accounting for adaptation & changing climate, fore-sighting, planning ongoing investment in infrastructure over decadal timescales	National infrastructure policy, financing, major policies for regions and sectors including coasts, communication and transport.	Infrastructure and logistic planning at international level

Social Assets and Infrastructure				
Scale	Local	District/Region	State/National	Global
Impacts	Increased social vulnerability and damage to other clusters affect health, livelihoods and community	Large-scale loss of production and/or natural and capital assets reduce livelihoods, income and amenities	Large urban and/or rural regions become moribund with a loss of public income, stagnation at the national level	Global impact burden leads to reduction in national impacts, loss of security in key regions
Risks	Reduced health and livelihoods, reduced amenity, endemic poverty	Loss of health, livelihoods, community connectedness, migration out of region to unsustainable levels	Outmigration of people, business and institutions to other states and nations	Globalised spread of poverty, walled off areas of privilege
Risk propagation	External resources required to sustain local amenity	External resources required to maintain order and supplement local rate base	Large migrations cause issue with displaced people, loss of taxation income	Regional loss of security requiring international intervention, mass migration
Adaptation policies	Significant adaptation will be required in other clusters contributing to loss in addition to social programs	Significant adaptation will be required in other clusters contributing to loss in addition to social programs	Triage taking place where limited resources for adaptation are at a premium	Significant regret that mitigation was less successful than it should have been. Triage at international levels

Natural Assets and Infrastructure				
Scale	Local	District/Region	State/National	Global
Impacts	Degradation and loss of natural goods and services and underpinning processes at local level	Degradation and loss of natural goods and services and underpinning processes at catchment level	Widespread degradation and loss of natural goods and services and underpinning processes, major systems threatened or lost (e.g., GBR, MDB)	Loss of regional environmental security across multiple countries requiring international response
Risks	Local loss of income and/or ability to operate, tourism and recreation affected	Regional loss of function and amenity affecting production, increased costs of natural resources or replacement of ecosystem function	Major loss of ecosystem function, regions become moribund, population movements affected by environmental security	Environmental refugees, loss of regional function and security
Risk propagation	Unsustainable adaptations made to relieve environmental pressure	Loss of skills and populations as people move away	Concentration of pressures into particular regions, accrual of unsustainable adaptations putting pressure on regions and budgets	Inability to manage environmental security having a flow on affect to other regions
Adaptation policies	Increased community involvement in environment, better monitoring and understanding of ecosystem process	More integrated management at catchment and regional development scale, ecology and economics are integrated	Biodiversity funds, national monitoring, supply of adaptive capacity to smaller scales, R&D, increased investment securing long-term returns	International treaties enabled, increased international co-operation including R&D and funds

Public-private policy strategies

Government and markets both have roles in managing rapid change and there different strategies for pursuing an appropriate mix. (Jones et al., 2013) suggest four policy-based scenarios:

- **Business as usual** – Governments and financial markets have a low sensitivity to resource limitations. Prices for resources are set based on short-term availability (supply and demand) and government regulation focuses on managing the flows of these resources rather than their stocks. Decision making for both the finance sector and government does not take into account limits to resources.
- **Price driven change** – Governments have a low sensitivity to resource limitations, while markets have a long-term outlook of the stock availability of resources. Price signals within the market are set based on the long-term availability of resources. However, no regulation is put in place to manage the availability of resources.
- **Regulation driven change** – Governments operate on a long-term basis and regulate the stock of resources rather than the flows. The market responds to regulatory change in a short-term way. The feedback from market change to policy development is not always effective.
- **Consensus driven change** – Governments and the market operate on a long-term basis by pricing and regulating the stock of resources rather than the flows.

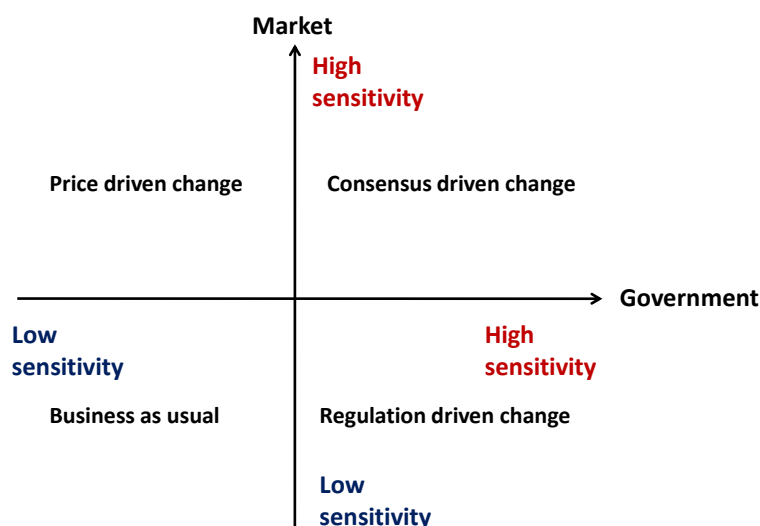


Figure 32. Scenario map showing sensitivity of the governments and financial markets. Each quadrant corresponds to one of the four scenarios (Jones et al., 2013).

Their preference on the basis of a future resource constrained world was the consensus-driven change. We believe that rapid change in climate produces high sensitivity to changing risks in both government and the private sector, suggesting that

a cooperative consensus driven model for policy change be developed to better understand and manage the resulting risks.

Key areas of responsibility

Risks crossing institutional domains are likely to create new and heightened vulnerability, redistribute the ownership of risks and make a lack of ownership visible in areas where vulnerabilities become acute, if not managed proactively. Figure 33 shows risk propagation across domains with the need for adaptive response following the direction of risk and the need for resources to meet increased demand for adaptation. Both governance and capacity will be needed at multiple scales. Key areas of responsibility for activity are summarised below:

Local government

Local government's primary purpose is at the implementation level with particular respect to planning, risk management and operations. It has the most direct links to the community, receiving important community feedback ([Productivity Commission, 2012](#)), and therefore has a key role in the provision of information and monitoring and evaluating of actions at the local level. The propagation of shocks through the system is likely to exceed the current capacity and resilience of local government to prepare and respond to these events. Extra resources will be required from the state and federal levels to support adaptation actions. Project governance is particularly important at this level.

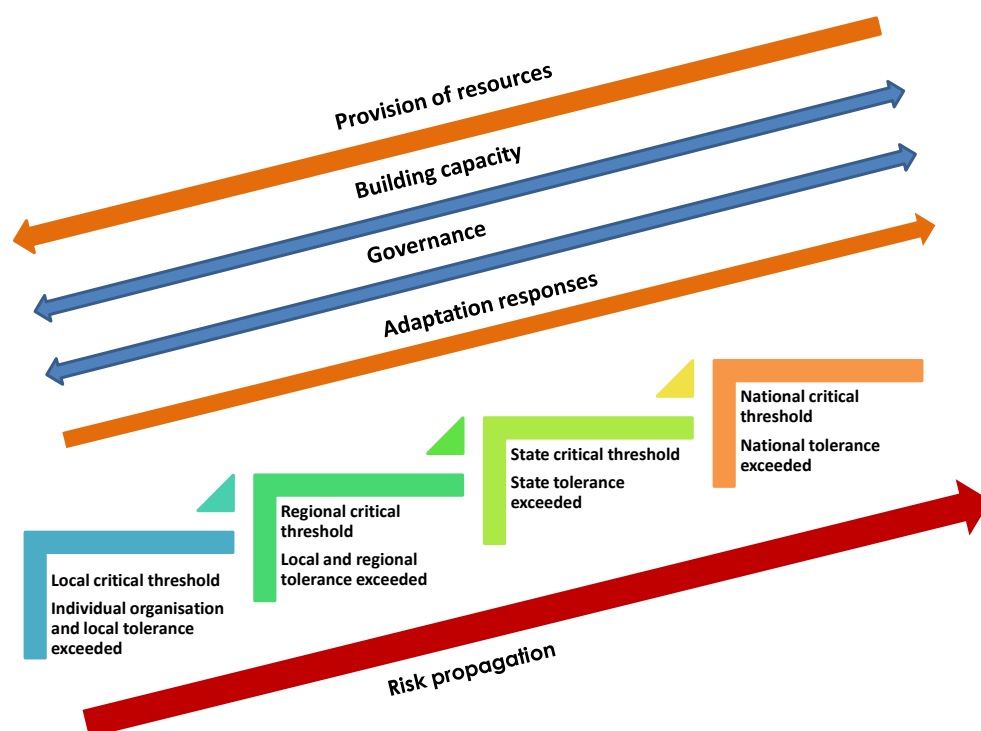


Figure 33. Diagram of risk propagation across domains showing the need for adaptive response following the direction of risk and the need for resources to meet increased demand for adaptation.

State governments

State government can support capacity building and work with local government to develop projects in this area. State-based policy-makers will need to consider the development and oversight governance that includes monitoring and evaluation processes for adaptation actions.

Planning may require coordination at the national level through COAG to achieve consistent management and property rights. Mechanisms that enable greater levels of cooperation between state and local government with the private sector will also be needed. Further clarification of roles and responsibilities across different government levels (local, regional and state) in key areas such as coastal planning and emergency management are also needed ([Productivity Commission, 2012, p 121](#)).

Federal government

The increased propagation of risks will require more activity at the national scale, both in planning and in response. The Federal Government provides oversight at a national level, assisting with coordination and resourcing of activities across state areas. It sponsors national programs of research and monitoring the results of which need to be made available at the state and local levels. Renewed research programs to investigate re-orienting climate research from its gradualist framing to concentrate on the understanding of the causes and effects of the rapid changes detailed in this report is a priority. The provision of communication and policy to enable leadership and proactive decision making is also important.

Industry

Industry will need cooperation from government to develop the regulatory frameworks for new products and markets. Innovation will benefit large businesses but small to medium enterprises (SMEs) will also need to build a better understanding of their exposure to risks and of potential opportunities. Greater clarity around disclosure and legal liability is needed. Information provision that is sector-specific is also necessary to assist in planning. Accessibility to information is especially important for SMEs and especially micro businesses. Investment is also needed to support markets for adaptation goods and services and to support the transformations needed to build resilience.

Civil society

Community understanding of adaptation is varied and needs to become much more proactive. Populations in vulnerable regions potentially subject to rapidly changing risks need cogent information as a matter of public safety. Vulnerable communities, individuals dependent on welfare, people from culturally and linguistically diverse (CALD) backgrounds, and elderly people have specific communication needs. Successful adaptation, particularly transformative actions can be promoted as exemplars and communicate widely. Specific investment will be needed to support the development of resilience in both soft and hard infrastructure particularly in communities that have limited resources and high exposure under rapid change. Mechanisms that enable the community sector to contribute to key plans and policies will assist in expanding the responsibility for risk management across civil society ([ACOSS, 2013](#)).

Policy for infrastructure

Queensland Community Recovery Minister David Crisafulli said that current federal policy rules for infrastructure only allow for like-for-like reconstruction.

"It is absurd that we continue to replace the same bits of infrastructure with like for like and it gets ripped up," he said.

"In some cases I've stood on bridges that have been replaced three and four times in the last five years." (ABC News February 4, 2013)

The long-time spans of fixed assets provide an opportunity to consider future needs and build back better. Current regulation and policy such as Natural Disaster Relief and Recovery Arrangements support this, and the recent inclusion of the Provision of Betterment Funding that will provide partial costs of essential public assets. However some assets do not qualify for this and local government may lack the funds to improve infrastructure to the required standard. Mechanisms that combine the needs of both soft and hard infrastructure are needed at to ensure the development of effective actions that serve the communities they are designed for.

Summary

As extreme events are likely to become more frequent and cascade together under rapid change, the need to start developing transitional policy to adapt to these extremes becomes increasingly important. Future policy outcomes in this area will need to be informed by a comprehensive understanding of the value impacts of these events and the risks they pose. Key tasks for future policy-makers will need to include:

- delegation of ownership and responsibility of risk, in particular risks that are un-owned at the institutional level;
- building of capacity; and
- transitional and transformative outcomes.

This will require:

- The rebalancing of competing agendas in both public and private sectors (e.g., imposed economic efficiency that reduces resilience, tightly regulated programs that reduce adaptability, highly programmed policy that reduces innovation).
- Mechanisms that allow for improved coordination across the Government, community and private sectors. For example, integrated policy frameworks that lead to complementary rather than competitive working arrangements.
- A greater emphasis on planned transitions over multiple time frames, with less focus on the very short-term, and a greater emphasis on innovation and transformation.
- Better understanding of realistic tangible and intangible costs of rapid change across short, intermediate and long-term time frames. The inclusion of non-monetary values, as identified in the adaptation clusters as part of this evaluation process.

Key policy opportunities:

- The potential for combining risk governance across policy portfolios. For example, measures to protect the security of essential infrastructure and services from extreme events are compatible with those for dealing with military security.

- Combining mitigation and adaptation in the management of natural assets to assist productivity and sustain rural regions through investment.
- The inclusion of local government and the community sector as part of the COAG process.
- Mapping and integration of relevant current policies across departments and different levels of government.
- The inclusion of innovation frameworks in policy and operational systems.
- The development of economic tools and frameworks that enable multi criteria assessment.
- Further development of knowledge and communication in this area that is sector and context specific.

3.5 Implementation

3.5.1 Question-based process for policy assessment

This report challenges the status quo for the application of climate change science to impact and adaptation assessment and of the tools used to evaluate and cost adaptation options. It has also discussed the notion of risks crossing institutional domains, of risk 'ownership' in that context and of adaptation at the institutional scale. These are all unfamiliar topics at both the policy-making and practitioner level. They will require new ways of thinking and of working. For that reason, the policy guidance being developed by the project in its final phase will be query-based. The following set of draft questions are intended to assist policy-makers think through the process of assessing actions needed for rapid change (Table 21).

Table 21. Key questions for policymakers

Key questions	Considerations Note that all questions can apply to single or multiple situations.
What is at risk?	<ul style="list-style-type: none"> • What is the nature of the risks faced? (e.g., fire, flood sea level rise, extreme winds, droughts, heatwaves, cyclones, heavy rain or a combination of these; inc. frequency and magnitude). • Who and what is at risk? (What are the domains impacted by this risks?) • How are they at risk? (How are these domains impacted by these risks?) • How do these risks operate across short, medium and long-term horizons? (Are these risks acute, chronic or cumulative?) • Are these risks likely to cross domains? (Where are the institutional thresholds for these risks? i.e., what are the levels of tolerance?)
What values are at risk?	<ul style="list-style-type: none"> • How are they valued? (What currency/currencies are being used to value e.g., political, social, economic, environmental, fiscal, cultural?) • Who values them? • How to the different values associated with these risks interrelate? • Will these values be compromised if no action is taken? • Over what time and geographical area are the costs of impacts being calculated for?
What are the solutions required to address these risks?	<ul style="list-style-type: none"> • What solution options are available? • Are these solutions needed to address these risks known and can they be applied? (Do the solutions have to be developed?) • What is needed to enable the solution? (resources, policy, processes) • What is the time frame for this solution to be implemented and used? • What are the risks associated with implementing the solution? • What are the criteria for assessing the most preferred adaptation option (effectiveness, cost, value?) • Who has responsibility for these solutions (implementation, resource, monitoring and evaluation)
What governance is needed?	<ul style="list-style-type: none"> • Who provides governance? • What type of governance is needed? • Who should provide resources for this? (What financial arrangements are needed to achieve the desired goal?) • What is the capacity of the body/bodies involved in delivering this action? • How is this project to be evaluated
What are the benefits?	<ul style="list-style-type: none"> • What are the benefits? • Who will benefit? • How will they benefit? • What are the co-benefits? • Over what time scale can these benefits be realised?
What is the priority for this decision?	<ul style="list-style-type: none"> • Value – what value is being preserved by these actions? • Cost – is this action cost-effective?

Scenarios are a key tool in the adaptation process, but to date understanding of how and when to use these tools effectively in both the problem and solution phase of adaptation has been a source of confusion for many practitioners and policy-makers.

Scenarios are an enabling tool that can assist exploration of a situation that may occur and which has not been experienced in a way that enhances understanding. The high level of uncertainty about what the future means that it is not possible to *predict* what is going to happen but it is possible to *interpret* what the future might be to enable decisions to be made and actions to be taken. Scenarios are a structured process that combines both current knowledge and visions of the future in a way that allows the synthesis of a number of possible options from information compiled from diverse sources. Use of scenarios by sectors such as the military and business is well-established and is generally used to gain understanding and the development of strategies to manage risk and assist planning and action in the future.

In areas of innovation where new knowledge is emerging and uncertainty is high, scenarios provide a way of exploring possible outcomes and paths of action. *Regardless of how scenarios are created, they have been shown to alter people's expectations about the depicted events* Gregory and Duran (2001) and can assist with acceptance of idea. It is important that all types of scenarios are understood in terms of *indications of possible futures* rather than *predictions of a future* when they are being used.

Key phases where scenarios are used in adaptation are:

- scoping of projects or activities;
- synergy mapping;
- identification and assessment of climate risks;
- development and selection of possible solutions;
- development of shared understandings; and
- decision-making.

Scenarios are diverse in their make-up and are usually designed for a specific purpose. Some of the types of scenarios that can be used in adaptation area listed below:

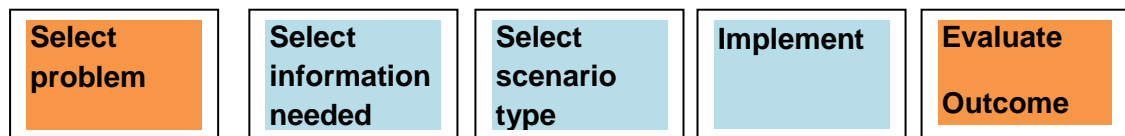
- Technical scenarios, where a number of 'modelled' options are presented. For example, CSIRO future climate scenarios, IPCC assessments. Adaptation Use: Support of decision-making in relation to planning, risks and policy.
- Risk based scenarios – these can be used to assess and prioritise risk. For example, scenarios that explore the likelihood of a number of possible risks. Adaptation use: Identification of risks through group-based scenarios for the analysis of risk.
- Actor-based scenarios where experiential learning is a key part. For example, mock trials to explore aspects of environmental law. Emergency exercises where mock situations are undertaken in a controlled environment to allow people to work through what they do in a situation such as a flood. Adaptation use: Training for responses to future conditions and possible outcomes and options, building of collaborative understandings.
- Situation-based scenarios where a situation is explored through a number of contexts. For example, business scenarios which examine possible future outcomes are explored by a group of key stakeholders. Adaptation use: Assessment of climate risk, exploration of adaptation solution options, collaborative solution finding, learning, synergy mapping.
- Back-casting scenarios – these take a future vision and work backwards, exploring what possible paths can be taken from this point in time to achieve

the desired goal. Adaptation use: planning support, exploration of solution pathways, building of collaborative plans of action.

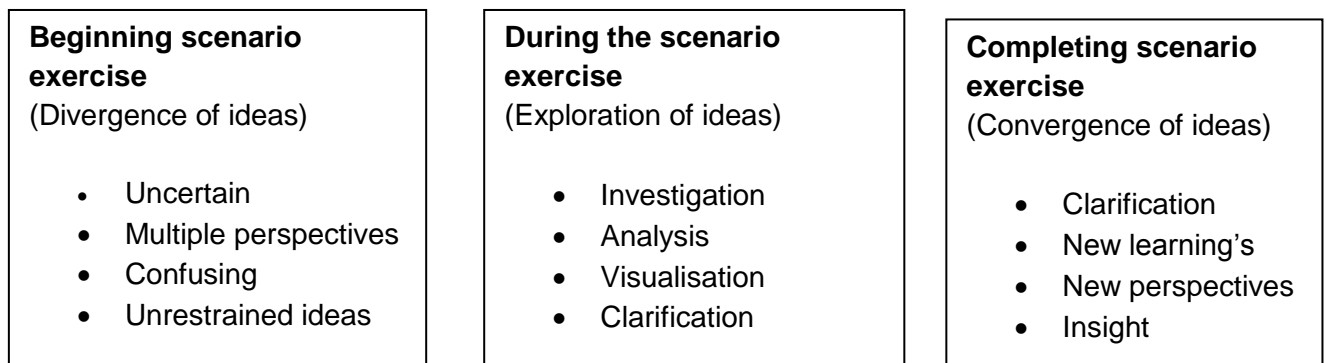
Using group scenarios

Due to the diverse stakeholders involved in the process of adaptation and the need for collaborative decision-making, group scenarios are particularly useful. They allow for aspects of ‘wicked problems’ associated with adaptation to be teased out in a collaborative way that can create new understandings and also capture new learning’s. Because this is a ‘creative’ exercise, having a rigorous process is important to ensure that ideas are guided and converge at the end. There is no specific time for a scenario and they can range from a brief afternoon session to one that is worked through over a number of days or months.

Key parts to planning the process are:



This process can be uncomfortable for some people because it requires that participants engage with the ‘messiness’ of the process at the beginning of the exercise (which is divergent), and work through the process of exploration to convergence. It also requires that they engage and accept ideas that may be different to their own during the scenario.



Key aspects needed for group scenarios:

- a clear purpose and structure that is specific to the task;
- plausible information that has credibility and can be justified;
- take into account the experiences of the people in the room;
- require reflection and sharing of ideas from the participants;
- guidance and facilitation rather than direction towards solutions; and
- documentation and synthesis of findings.

Using scientific scenarios is an important part of adaptation as they allow for credible data to be used to inform in a way that allows for interpretation into the context of the person using them. These scenarios can be in a number of forms such as in graphs, pictorial forms such as videos or GIS maps, spoken or written in reports. These sorts of

scenarios will particularly important for assisting decision making under rapid change which requires the exploration of a number of options across a diverse range of areas.

Credible scenarios of rapid change can be derived from climate model output and used to test action situations at the institutional scale. These can be used to evaluate the circumstances under which domains might be crossed and therefore to evaluate the need for adaptation at the institutional scale. Given the likely demand of changing extremes on policy needs, these would be a more timely scientific contribution than trying to develop predictive tools that may be delivered over the medium term.

The types of scientific scenarios needed for rapid change will include scenarios that examine:

- Future hazards across a range of different contexts;
- Climate scenarios that are able to calculate the possible effects of multiple or cascading events and the interactions between geographical and social aspects;
- Institutional scenarios that examine where the possible thresholds might be and the consequences of crossing that threshold; and
- Integrated scenarios that explore possible adaptation options and solutions in relation to rapid change.

The development of a range of creative media to portray scenarios of both climate and impacts would also be useful.

3.5.2 Application of economic tools

A significant implication of rapid change for Australian governments is that government itself, businesses and communities may not have adequate time to engage in the autonomous adaptation anticipated by models built under the assumption of gradualism. Without policy that accounts for the possibility of rapid change, costs will increase as social, environmental and financial impacts are experienced faster than anticipated. Instead of gradually making the transition from one state to another, businesses and communities are likely to be subject to rapid changes. This may result in unanticipated damages and reactive responses that increase expenditure and potentially lead to maladaptive responses.

This project has described a variety of economic tools for valuation and costing that each have strengths and weaknesses, but that collectively suit a wide range of circumstances. We have also demonstrated the important of process in decision-making, particularly in circumstances where values are uncertain or contested and where both problems and outcomes cannot easily be predicted. This section provides a broad framework for the selection of tools and methods described throughout Section 3.4.

Selection of economic tools

Uncertainty is a key determinant in the selection of economic methodologies for climate adaptation decision-making, as shown in Figure 34. Problem uncertainty on the vertical axis describes predictive uncertainty, where external drivers and internal processes produce uncertain futures. Solution (outcome) uncertainty is also often hard to predict, especially at the institutional scale where it will be affected by a large range of internal and external factors.

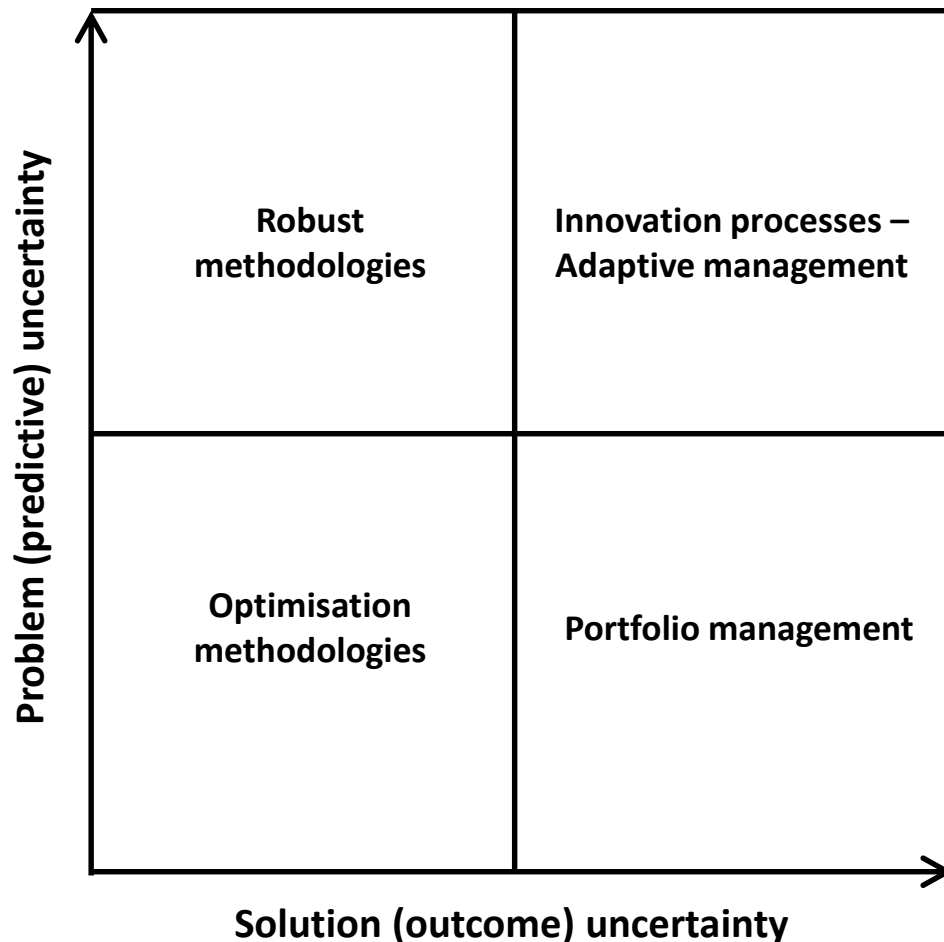


Figure 34. Problem/solution uncertainty matrix with economic strategies.

Optimisation methodologies

These can be used when uncertainty around both the problem and the solution can be constrained in some way. Given that uncertainties under climate change will be greater than for most other purposes, many of the modifications for such methods suggested in this report and by authors such as [Hallegatte \(2009\)](#); [Hallegatte \(2011\)](#); [Hallegatte et al. \(2012\)](#) and [Quiggin et al. \(2010\)](#) will still need to be used.

Methods suitable for this type of assessment include cost benefit analysis, cost-effective analysis and multi-criteria analysis. The valuation of impacts separately to the costing of adaptation options may be needed.

Portfolio management

Portfolio management works best when problem uncertainty can be constrained but the potential success of adaptation measures remains uncertain.

Portfolio management is a term used in the finance sector and refers to the concept of risk spreading. By not putting all the adaptation eggs in one basket, the risk of widespread maladaptation due to uncertainty is reduced because the chances of some approaches being successful are increased. Not all adaptation actions will yield significant benefits, however the spread is wide enough so that some will ([CCS, 2011](#))

and those can be diffused amongst other actors. These strategies are likely to be most successful in market-dominated situations.

For example, diversifying the tourism industry to take advantage of both summer and winter seasons means that the industry is viable under various future tourism trends ([CCS, 2011](#)). Because risk is diversified, the capacity to take on trial risk, despite uncertainty, is enhanced. The use of trials and suites of adaptation measures also allows for community-driven approaches and iterative learning.

The suite of tools that can be used here is similar to those for optimisation methodologies, but monitoring strategies become much more important in order to gauge the success of different trials.

Robust management methodologies

Robust management methodologies come into play when problem uncertainty is high, but when the solutions are fairly well understood. Because this set of methods has been discussed in Section 3.4.3, the reader is referred to there and the literature therein.

These methods are very flexible and can utilise a wide range of tools.

Innovation processes and adaptive management

Innovation processes and adaptive management become necessary when both problem and solution uncertainty are difficult to constrain. This will happen in a range of complex settings where risk is best managed through innovation processes.

As described in Section 3.4.4, a range of innovation processes being used in business and other areas of deliberative can potentially be brought into the adaptation arena. Adaptive management has been widely promoted in the sustainability and resilience literature but has not been used as widely and successfully as hoped. This may be because innovation processes have not been widely incorporated into adaptive management.

This type of process is not amenable to conventional economic tools but such assessments, which always should involve stakeholders in interdisciplinary and transdisciplinary collaborations, may well involve a variety of economic tools in a larger valuation process. The choice of which tools to use will be highly context specific. Innovation processes most need the development of 'soft' or socially-dominated infrastructure.

A major strategy that requires both innovation and adaptive management processes is transformation. Rapid change increases the need for systems to transform, especially if they are to suffer severe or irreversible damage in their current state. Transformation takes considerable resources, requires the involvement of key actors and often requires assessments that look beyond the obvious to ensure that maladaptation does not occur.

Values at risk

Capital assets and infrastructure are identified as being a central theme for climate adaptation. These assets have lifespan, and consequently decision horizons, at the same scale as climate change (hundreds of years). Furthermore, because they are physical entities in the environment, climatic conditions are significant. These two

characteristics make capital assets and infrastructure particularly climate-sensitive. Water infrastructure, building and house and transportation infrastructure are particularly exposed to climate change, and decisions taken today will have significant impact under climate change. Likewise, energy infrastructure, critical to transportation and production, is often climate-sensitive due to its coastal location.

For settlements and physical infrastructure, long-term planning is one of the most effective ways of reducing long-term risk; for example, urbanisation plans that account for flooding risk. Taking long-term decisions in an era of uncertain (potentially rapid) climate change means that infrastructure decisions need to be robust.

Social assets and infrastructure are also very climate-sensitive because decisions have consequences over long periods of time. Land-use planning is particularly exposed to climate change and decisions taken today will have significant impact under climate change. Social assets are difficult to capture and quantify monetarily, and social infrastructures are dependent upon uncertain future socio-economic conditions. Here we see that a collaborative and iterative process of decision-making that captures multiple stakeholder conceptions of value may be applicable.

Natural assets and infrastructure are also identified as being very climate-sensitive and decisions have consequences over long periods of time. Ecosystems are not simply capital to be protected in their own right. Their functioning is intrinsically linked with the adaptability of all human systems to climate change (Hallegatte et al 2011). Coastline and flood defences are particularly exposed to climate change and decisions taken today will have significant impact under climate change (Hallegatte 2009).

In regards to the goods and services sectors, direct decisions do not have quite as long time horizons as infrastructures; however the sectors are dependent upon the quality, structure and functioning of capital, social and natural assets. Therefore, long-term decision-making regarding these assets and infrastructures impacts the goods and services sectors. This interconnection highlights the possibility of risks crossing domains and the need for integrated decision-making at the institutional level. This decision-making would utilise multiple methodologies to inform the process at appropriate points.

Adaptation across institutions

The sections above outline key considerations on the issue of institutional-level adaptation and governance, particularly where risks cross domains.

Planned adaptation, and responses to events will also differ across the institutional scale, with the federal government doing national economic planning, large scientific research programs, policy design for specific sectors (water, agriculture and forestry), state government doing planning and program delivery in many areas including regulation, and local government being the interface between the economy, society and environment at the local scale.

The Federal Government has a direct role in adapting existing and planned infrastructure to climate change. This includes transport networks, energy, water and telecommunications networks. These responsibilities also overlap and interact with State-level responsibilities.

In regards to long-term national-level planning we argue that the political process of prioritising economic trajectories, ecological preservation and sociocultural values is complex. Optimisation techniques may be important at the federal level in order to

explore high-level trajectories and potential trade-offs. The outputs from such optimisation would ideally be used as an input into a broader decision-making framework.

At the state level, many planning and regulatory responsibilities have very long time horizons and are very exposed – such as urbanisation plans and building design and standards. Land-use planning must contend with multiple stakeholders and values and is dynamically interconnected with environmental, climatic, economic and sociocultural factors. Similarly, local level planning is extremely climate-sensitive and has long-term impacts.

Public (government)-based climate adaptation has the interests of all constituents, groups and businesses at its core, not simply government-owned assets. The role of government in adaptation has been widely identified to facilitate private adaptation and build resilience. Current approaches to government decision-making incorporate multiple considerations including traditionally defined economic efficiency, equity and vulnerability, and long-term preservation of natural and cultural assets. In public and private decision-making and from the local to the Federal scale, such values are not routinely assessed using economic tools. A wider use of different economic tools would help to quantify ‘intangible’ values, thus making them more visible and per chance giving them higher priority in decision-making. The role of discounting in assessing long-term values at risk, and in weighing up the cost of adaptation with the social returns of adaptation, needs to be examined closely and recommendations provided for practical use.

Both optimisation and robust techniques are essential to the adaptation process. To ignore either would be folly, as they both have appropriate applications and bring important analysis to the decision-making process. The most important economic method to explore at the institutional scale, though, may be transformation. Exploring its role in adaptation to rapid change is a priority.

4. GAPS AND FUTURE RESEARCH DIRECTIONS

The objective of this study is to develop an economic methodology at the institutional scale to support decision-making on adaptation actions and investments ranging from adjustment to transformation, given the likelihood of rapid changes in regional climate leading to rapid changes in extremes and accompanying risk of disaster.

This report has endeavoured to develop an economic methodology that fulfils these aims and in Section 3.5.3, we provide a broad framework for doing so. However, we have not managed to fully integrate the institutional scale in to this framework, despite developing Ostrom's IAD framework for this task. The issue of domains, risk propagation across domain boundaries and risk ownership is an important one that needs to be explored. So too, does the task of planning adaptation at the institutional scale to ensure that capacity and governance is adequately managed.

Of the aims detailed in Section 1:

- Understand the appropriate mix between public and private adaptation and risk sharing;
- Understand the impacts of changing climate extremes on the economics of valuing adaptations;
- Identify critical points where the economics of adaptation has not yet integrated recent findings from climate science and offer suggested improvements; and
- Identify valuation tools for end-users that cope with the realities of uncertain damage functions, ambiguous climate futures and the potential for non-marginal change.

We believe we have made progress in all four aims. These are briefly summarised in the following section.

Summary and next steps

The questions asked in this project are not easy to answer because existing scientific and institutional structures are not structured to address them. In previous sections we articulate reasons for this.

These reasons include:

- The framing of climate science around predicting future climates using the signal to noise model. The interpretation of model results using reproducible patterns of mean change as a measure of model skill favours the scientific narrative of gradual change.
- The scientific narrative of balance and conforming to the mean has thrived since the scientific enlightenment over two centuries ago. This narrative has informed both the physical science and economics (which uses the mathematical tools of classical physics more often than not, even though physics has moved on). This mutually reinforces the use of tools that map gradual change and optimisation in both science and economics.
- When this is added to the proposition that the current costs of climate change are negligible or scientifically unattributable, and therefore 'unprovable', any urgency to be proactive in managing climate change extremes is dissipated.

- The science of impact assessment is concentrated on models that (appropriately) simulate a wide range of conditions but are not structured to assess extreme events. Some of these models are national in scope but others are local or regional. A national capacity exists for grazing and major crops, and is being developed for water resources but does not exist for flooding, cyclone damage, severe storms, coastal impacts, wildfire or severe heat. Nor is there any serious capacity to investigate the joint burden of such hazards.

This report has explored recent rapid changes in climate, its origins, potential impacts and the possible consequences of such events continue to escalate at an institutional scale. In particular we have examined the notion of risks crossing institutional domains and risk 'ownership' in the context of rapid change. This has brought into question the current economic and science generated tools used for impact and adaptation assessments and the way they are being used to evaluate at a practitioner and policy level. Valuation of adaptation under rapid is complex and current systems and frameworks are not adequately able to value or cost this.

This report also examined current economic tools, systems and policies to see how they create barriers and they might be of use in addressing these sorts of events. In particular, the economics of disaster and resilience and the associated policy and innovation frameworks and their use in relation to rapid change.

COAG has instituted a process of dealing with emergency management to disasters, a significant component of which is the principle of proactively mitigating risks to future hazards rather than relying solely on improved emergency response. This process has been catalysed by the recent burden of extreme climate events on the economy and communities.

Policy responses for this latest generation of disaster management strategies are framed according to the language of resilience, breaking down institutional silos and community engagement. However, the language of extreme events is still focused on the construct of random variability surrounding gradual change. Therefore, the dual policies of adaptation to climate change and improving disaster response have not yet been integrated to the degree they need to be if the risks of rapid climate change are to be dealt with seriously.

The idea that markets can adapt to gradual change occurring far off into the future is also challenged in this report. The potential for rapid increases in climate extremes to lead to risks crossing domains will affect both public and private interests, but will tip the balance for action from markets to policy. However, the need to adapt will be shared by both public and private institutions as does the task of determining who might take responsibility for un-owned risks under climate change. Ownership may rest with individuals as well as organisations and institutions. New arrangements between public and private interests and between government, industry and the community will need to be explored.

A key finding of this report is that future rapid change, if not prepared for, poses a major risk to our communities and their future sustainability. Effectively addressing such issues will require new ways of thinking and working which include the following:

- The guided transformation of current institutional structures and systems. In particular the development of collaborative frameworks that enable decision making within and across a number of institutions and frameworks to assist with decision making under uncertainty.

- The development of fit for task economic frameworks, capable of integrating and assessing a diversity of costs and values across different time scales. In particular ‘intangible’ costs need to be included more fully in these assessments. The disparity between different discount rates used in different institutional settings needs to be addressed.
- The integration into adaptation practice and policy of frameworks and methods that are iterative and reflexive, such as innovation and assurance processes. These are already in use and have established mechanisms that allow for: decision-making with uncertain outcomes, the introduction of new ideas and technologies, social interactions, knowledge development and collaboration across a broad range of stakeholders.
- Further research to better understand the full ramifications of rapid change and how it will impact current systems and institutions, especially to assess where possible thresholds might be and where they cross institutional domains. In particular the development of models that include different types of extreme events in a number of contexts and sequences.
- Development of capacity through appropriate resourcing, the development of knowledge and communication that is ‘fit for purpose’ for end users and governance to support this.

Future research directions

The research described in this report is largely in the discovery and exploration phase. Tasks that would benefit from further development and funding include:

- Identify underlying social, economic and natural systems influence particular thresholds and at what point they cross into other domains.
- Assess current frameworks and tools that can be applied to assist valuation, monitoring and evaluation of adaptation under rapid change; e.g., innovation based tools and methods used in business.
- Assess current adaptation governance and how it is being applied, mapping of current institutional approaches to assessing climate risk and impact propagation across domains.
- Examine how climate risks propagate across domains and along timelines, and how those risks are likely to respond under rapid change. This would include the valuation of primary and secondary impacts.
- Analyse of how ownership of key values vulnerable to rapid changes in climate are shared across institutions. Identify where responsibilities for managing those risks lie and identify un-owned risks.
- Assess the role of public and private finance in reacting to rapid changes. For example, the insurance industry plans on 1–2 year’s projected income from premiums – a sudden escalation of costs where reinsurance is limited can create premium and underwriting pressures.
- Identify vulnerable industry and community sectors under rapid change.
- Explore the role of narratives in adaptation decision-making – how and where they are used.
- Assess the role of land-use planning in creating legacy effects where new cohorts of residents and landholders can suddenly be exposed to risks they were unaware of when developing/buying a property.

Activities and research that could better support the above needs are:

- Improve the science of non-linear climate change, sufficient to develop credible scenarios that can be used to assess the propagation of risk at the institutional scale.
- Within the scientific community, re-visit how model skill is interpreted. Given that climate models contain step changes in key variables, develop measures of likelihood for the frequency and magnitude of such changes.
- Develop scientific narratives that accurately reflect the nature of change, recent climate events to be integrated into the adaptation narratives used by organisations. This may be a role for boundary organisations such as regional Climate Change Alliances and Industry Peak Bodies.
- Improve the ability of scientists to engage with the broader community in order to link their research with personal experiences of climate change, variability and adaptation.
- Improve ability of economists to engage with the broader community over values and valuation.
- Develop spatial models able to combine urban growth with future hazards to assess rapid changes in exposure to rapid changes in hazards. This is especially important for heatwaves, flash flooding and fire.
- Develop the institutional capacity to use a range of different methods to assess the value of adaptation.

GLOSSARY

Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, which seeks to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate (IPCC 2012).

Aggregate cost

Sum of the distributed costs of an event or set of events across a system that need to be collected in order to understand the total cost.

Cost-benefit analysis

Systematic process for balancing the costs and benefits of a project or action. It usually involves changes in marginal values over time discounted to allow for factors such as the cost of finance, preference for risk, the value of externalities and the cost of opportunity.

Cost burden

Cost borne by an actor in order to be able to operate.

Critical threshold

The level of system change or impact that prompts a response in terms of management, jurisprudence, legislative requirement or similar. Can often be managed at critical control points within a system.

Deep Uncertainty

Uncertainty that results from myriad factors both scientific and social, and consequently is difficult to accurately define and quantify.

Delayed costs

Sometimes synonymous with deferred costs, the costs ensuing from an action or event that occurred in the past.

Gradualism

The belief that a process changes by small, incremental steps over time (policy, evolution).

Learning by doing

The process of studying a set of actions to determine how they impact on the system being acted upon, and whether they are producing the intended outcomes. This is a reflexive process intending to maximise the benefits of acting and avoiding maladaptation.

Linear

A direct relationship between one or more variables that remains constant over time

Maladaptation

The adverse outcomes of adaptation efforts that inadvertently increase vulnerability to climate change. Action that undermines the future ability to adapt by removing opportunities and hampering flexibility is also maladaptive (modified from IPCC 2012).

Mean

Technical definition of average. The total of all values divided by the number of values in a sample.

Mean change

Change in the mean of a sample occurring over a specified amount of time.

Non-linear

A relationship between one or more variables that changes over time. This change may be gradual, abrupt or the relationship may cease to exist.

Reflexivity

An attribute of complex systems where cause and effect form a feedback loop meaning that actions taken can change the system itself. Reflexive decision-making in a social system has the potential to change the underpinning values that led to those decisions.

Secondary impacts

Flow-on impacts from primary impacts, e.g., economic costs from property damages.

Social Technology

After Arthur (2009), a technology has a purpose and is an assemblage of practises and components. It is organised around a central concept or principle, is modular and recursive, and therefore evolves over time. Social technologies are “soft” systems such as adaptation, democracy and legal systems.

Value-added

Calculation of industry contribution to Gross Domestic Product as calculated by the Australian Bureau of Statistics, largely gross output minus expenses.

APPENDIX A: ORIGIN OF THE GRADUALISTIC SCIENTIFIC NARRATIVE

Abstract

This paper describes the general structure, origins and influence of scientific narratives of climate change and how they have come to dominate formal and informal narratives used to inform adaptation. These scientific narratives have deep historical roots that have been used to measure, interpret and communicate climate science for well over a century. They are constructed around the signal-to-noise model of linear forcing and response relationships, and forecasting using such models. The resulting narratives describe climate change as a gradual process influenced by random variability. While such models are useful for attributing climate change and describing in general terms how climate may change with its attendant uncertainties, they do not adequately describe how the climate will change over the timescales that most inform adaptation. These timescales, extending from several years to several decades, inform how adaptation is carried out with reference to problem uncertainty (how risks may evolve), solution uncertainty (how likely solutions are to manage risks) and the life of specific decisions. Furthermore, narratives of gradual change are not fully supported by observations, climate models or scientific theory: rather, the available evidence points to climate changing in a series of steps punctuating periods of reduced or no trend. The construction of a gradualistic narrative suggests that climate change is remote in time and that there is plenty of time to adjust to such changes. The idea that climate can change abruptly, challenges the notion that incremental change can be responded to at leisure.

Introduction

Scientific narratives are important tools for explaining the cause and effect sequence of processes and phenomena interpreted from scientific theory. They are also key tools in framing how science is viewed within a broader social and cultural context, contributing to narratives of cultural origins and identity and framing themes around issues such as progress and risk ([Shackley et al., 1998](#); [Edwards, 1999](#)). While recent literature has explored how scientific narratives of climate change are influencing broader social narratives, especially via framing effects ([Jasanoff, 1996](#); [Hulme, 2009](#); [Jasanoff, 2010](#); [Viehöver, 2011](#)), there has been very little work on the first step: how science is developed into narrative. This is where formal scientific narratives are developed from scientific findings by the expert community that produces those findings. This process is important because scientific narratives influence how scientific findings are interpreted in both formal and informal settings.

For narratives informing adaptation to climate change, scientific narratives describe the way in which climate change is expected to change and by how much ([Edwards, 1999](#)). The narrative describing how the climate changes that is constructed by and shared within the scientific community informs climate scenario construction. These narratives in turn inform the construction of adaptation methods, but will also combine with others' experience of climate in the general community to inform how adaptation is carried out. The initial scientific narratives of climate change constructed by the scientific community are therefore critically important in shaping how subsequent narratives about adaptation are constructed.

The model we are using to explain this sequence of narratives is shown in Figure 12. This figure shows scientific knowledge as being constructed through narratives of how science is carried out; such knowledge becomes robust through review, criticism,

modification and consensus-building. Discipline-based narratives, such as those that accompany climate change, develop from these narratives but also develop their own modifications as a community of practice. These then inform broader public narratives but are also used to develop methodologies for assessing and managing risk. A recent literature has critiqued the framing of science communication to policy makers and the public by bodies such as the IPCC as carrying specific frames that influence public narratives and the perception of risk ([Hulme, 2009, 2011](#)).

However, there have been few assessments of the basic scientific narratives of climate change informing adaptation to see whether they properly assess the evidence of climate change ([c.f., Beven, 2002](#)). Most have concerned themselves with how scientific information is being framed for use in informing decision-making. However, there is a distinction between the straightforward communication of science and the communication of scientific information for risk ([Jones, 2011](#)), a distinction that has not been clearly recognised in the IPCC uncertainty guidance material ([Mastrandrea et al., 2010](#)). Obviously they influence each other, but also need to be recognised as different.

The communication of science for risk needs to take the nature of the problem into account but also relies on how the science is prepared and presented. The sequence of narrative development investigated in this paper culminates in the development of the gradualist narrative of how the climate changes. This feeds into adaptation narratives that plan to make incremental adjustments to impacts because they are only expected to become severe far off into the future and, in most cases, are assumed to be small in the present day.

The main thesis is that the communication of climate change as a gradual process is socially constructed through long-standing narratives of the scientific method that date back to the scientific enlightenment. The use of forecasting using such methods that has become the dominant method of constructing scenarios for calculating climate risks, serves to reinforce the gradualist narrative. However, the available evidence from observations, climate models and scientific theory points to climate changing in a series of rapid changes punctuating periods of reduced or no trend. This has significant implications for how adaptation is conducted and for the construction of scientific narratives informing adaptation.

The structure of the paper investigates scientific paradigms and their structure, summarising the knowledge claims, methods and tools and cognitive values associated with the current narrative of gradual climate change. It then goes on to look at the theory of climate change, finding that the overwhelming emphasis on gradual change is not supported by observations, climate models and the theory itself. The paper concludes with suggestions as to how to overcome this bias.

Scientific paradigms

Scientific narratives, 'stories about science', are drawn from scientific paradigms. Paradigms themselves contain not only scientific theory but have important sociological aspects. Narratives drawn from climate science describe how the climate is expected to change, so provide a major input into the decision-making and practice of adaptation. Scientists provide their expert summation of scientific knowledge but also make their own judgements as to how to frame that knowledge and as to what knowledge is relevant to the issues at hand (e.g., [Hulme, 2009, 2011](#); [Kitcher, 2011](#)). [Laudan \(1984\)](#) lists Kuhn's paradigms as containing:

1. Claims to knowledge of the world;
2. Appropriate methods and tools for studying the domains covered by the theory; and
3. A set of cognitive values or ideals attached to that paradigm.

According to [Masterman \(1970\)](#), Kuhn's paradigms have a strongly sociological aspect where aspects of a paradigm become identified with a particular group who invests their identity in these claims, methods and ideals. Here, we are interested in how hypotheses and theory become communicated as scientific "rules" and those rules feed into scientific narratives.

The climate science community has a very strong institutional structure overseen by the World Meteorological Organisation and exercised through programs such as the World Climate Research Program and those of the IPCC. The WMO and IPCC also auspice the development of methods for forecasting and prediction, assessing climate stationarity and change, climate modelling conventions and so on. These methodologies shape narratives as strongly as the science content they contain, so are critically important in how they shape decision-making.

Knowledge claims

The study of climate change is a branch of climatology. The role of greenhouse gases in changing Earth's radiative balance is part of the core theory of climate change, which is well established ([Pierrehumbert, 2011](#); [Sherwood, 2011](#)). As such, this falls into the area of science that Kuhn referred to as normal science ([Kuhn, 1962](#)). Continuing work developing this science can be described puzzle solving: unresolved questions are addressed without any expectation that the underlying core theory will be drastically changed, although it may be modified.

Claims to knowledge of how the climate changes are described by two competing hypotheses ([Corti et al., 1999](#); [Hasselmann, 2002](#)):

1. Anthropogenic climate change occurs independently of climate variability; and
2. Anthropogenic climate change interacts with climate variability.

[Corti et al. \(1999\)](#) stated:

"... a crucial question in the global-warming debate concerns the extent to which recent climate change is caused by anthropogenic forcing or is a manifestation of natural climate variability. It is commonly thought that the climate response to anthropogenic forcing should be distinct from the patterns of natural climate variability. But, on the basis of studies of nonlinear chaotic models with preferred states or 'regimes', it has been argued that the spatial patterns of the response to

anthropogenic forcing may in fact project principally onto modes of natural climate variability.”

The first hypothesis supports a gradual climate response to forcing, whereas the second would result in nonlinear responses that would also affect extremes. The key to deciding between these two hypotheses is in assessing climate behaviour over decadal time scales.

Research on this point has been inconclusive, with evidence supporting both alternatives. [Seidel and Lanzante \(2004\)](#) investigated temperature records from surface to the stratosphere testing a number of alternatives: linear trends, flat steps, piecewise linear and sloped step. They decided that for surface data (1900–2002), the piecewise linear and sloped step were the best statistical models. For upper air data, conclusions were more elusive. Results for tropospheric (mid and upper atmosphere) data (1958–2001) suggested that most warming occurred in the climate regime shift of 1977. Stratospheric cooling could be explained by both step and trend and simple trend models.

These two hypotheses also influence weather and climate predictions. [Lorenz \(1975\)](#) identified two kinds of predictability:

1. The first kind is due to initial conditions with fixed boundary conditions. It is associated with weather and shorter term (interannual to decadal) climate predictability, and
2. The second kind is due to changing boundary conditions with fixed initial conditions. It is associated with long-term (multi-decadal to centennial) climate predictability ([Lorenz, 1975](#); [Hasselmann, 2002](#); [Collins et al., 2011](#)).

The first kind provides a temporary window of predictability before a system becomes too chaotic to predict with any skill. For weather forecasting, this is seven to ten days. In the second kind, outcomes are bounded by external forcing; e.g., as in the climate system response to $2\times\text{CO}_2$. A climate model run multiple times under the same greenhouse gas scenario will show significant uncertainty in its early stages but reproduce very similar trends over long periods ([Meehl et al., 2007](#)). Forecasting climate over decadal timescales and longer subjects climate models to both types of predictability ([Collins, 2002](#); [Collins and Allen, 2002](#)).

Decadal-scale climate processes such as the North Atlantic Oscillation and Pacific Decadal Oscillation are widely recognised as having several modes that they will switch between, sometimes individually and at other times in concert ([HM Treasury, 2003](#); [Schwing et al., 2003](#); [Rial et al., 2004](#)). Such regime changes affect a range of systems including fisheries, agriculture, water resources and marine and terrestrial ecosystems ([Ebbesmeyer et al., 1991](#); [McCabe and Wolock, 2002](#); [Rial et al., 2004](#)) and change the frequency and magnitude of extreme events ([Warner, 1995](#); [Erskine and Warner, 1998](#); [Swetnam and Betancourt, 2010](#)).

Changes in decadal-scale oscillations have also more recently been implicated in changes in the rate of global mean warming ([Tsonis et al., 2007](#); [Swanson et al., 2009](#); [Swanson and Tsonis, 2009](#); [Wang et al., 2009](#)).

While decadal variability is widely perceived as undergoing rapid regime changes due to stochastically-generated processes ([Rodionov, 2005](#); [Overland et al., 2008](#)), its role under the alternative hypotheses – independence or interaction with external forcing – is agreed to. Independence means that climate extremes will change at random, while interaction has the potential to produce systematic non-linear changes with

unpredictable timing. However, when we move to the methodological aspects of the climate change paradigm, the balance between these two hypotheses becomes almost totally one-sided.

Methods and tools

The dominant method of interpreting climate change as outlined in Section 2.5 is the STNM. [Santer et al. \(2011\)](#) describe it as: *the warming signal arising from slow, human caused changes in atmospheric concentrations of greenhouse gases is embedded in the background ‘noise’ of natural climate variability*. This method selects hypothesis 1 as the working model of how climate changes in preference to hypothesis 2.

The anthropogenic warming signal is assumed to change smoothly as in Figure 35, with natural variability expressed as noise around that signal ([e.g., Swanson et al., 2009](#)). Figure 35a and b both represent information about temperature change from a single climate simulation; Figure 35a shows the raw annual data from that simulation, Figure 35b shows the signal interpreted according to a line of non-linear best fit and Figure 35c interprets this data as a series of statistically significant step changes separated by trends that show varying degrees of statistical significance.

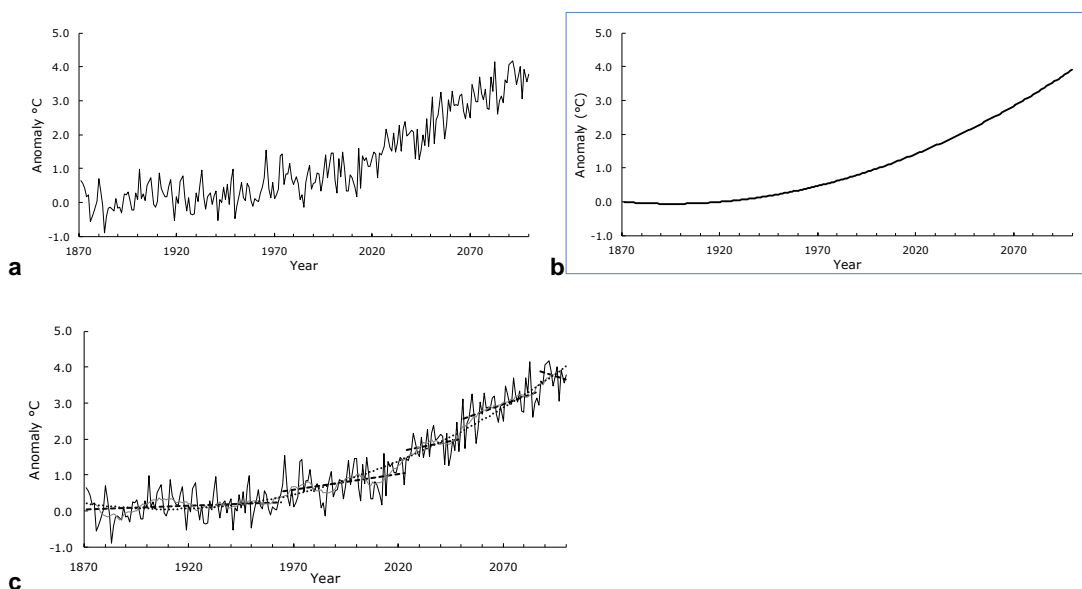


Figure 35. Single climate model simulation for south-east Australian minimum temperature (CSIRO Mk3.5 A1B $T_{min_{AGW}}$) showing a) the mean, b) annual variability and c) mean, annual variability and step changes for a high emissions pathway.

Figure 35b represents the STNM and Figure 35c suggests that abrupt changes are occurring in the direction of the long-term trend, potentially leading to rapid changes in extremes. This aspect of variability is non-random with respect to mean change but is positive with respect to the direction of change. Figure 35b represents hypothesis 1 whereas Figure 35c favours hypothesis 2, although this is not the only way by which hypothesis 2 may manifest. The time series in Figure 35 represents anthropogenic warming in minimum temperature for south-eastern Australia, attributed using the method of Jones (2012), so explicitly supports this hypothesis because it shows an episodic, regional warming signal.

However Figure 35b is almost invariably the way in which regional climate change is represented for decision-making. Despite the presence of two competing scientific

hypotheses, the STNM has become the dominant influence on how climate information is analysed and communicated for impacts and adaptation studies (e.g., [Hulme and Mearns, 2001](#); [Murphy et al., 2009](#); [Christidis et al., 2011](#); [Hawkins and Sutton, 2011](#)). The image of a gradually changing climate leads to adaptation being widely considered as a series of gradual adjustments to such changes (e.g., [Evans, 2009](#)). This in turn is the dominant scientific narrative informing decision-making on adaptation.

However, other methods are used to investigate how climate changes at the multi-decadal timescale. Of five methods investigated for assessing naturally- and anthropogenically-forced decadal climate variability ([Solomon et al., 2010](#)), two depend on the signal to noise model: Analysis of Means and Variance (ANOVA) and Empirical Orthogonal Functions. Of the remaining three methods, one: optimal fingerprinting requires large ensembles and does not distinguish between naturally and externally forced trends. The remaining two: linear inverse models that subtract specific modes of variability to estimate the signal and initialised climate model hindcasts simulating historical decadal variability with observed climate change (e.g., from pre-industrial to the current day) have not been widely applied. The method applied in [Jones \(2012\)](#) and used to analyse and display Figure 35c is a linear inverse model.

Detection and attribution (D&A) studies are also dominated by the signal to noise model ([Hegerl et al., 2007](#); [Hegerl et al., 2010](#)). Changes in extremes are attributed using the signal to noise model, but because of extremes' generally greater variability, statistical significance is much harder to obtain ([IPCC, 2007c, 2012b](#)). Significance can only occur when the greenhouse enhanced extremes exceed the variability measured under control conditions. The rarity and high variability of extreme events means that for most variables, temperature excepted, obtaining significance requires a long period of observation before statistical significance can be obtained.

The assumption that the human-induced effect on changing extremes is gradual means that any non-gradual changes in extremes will be interpreted as climate variability – such changes, if they occur, may have to persist for some time before being considered as statistically significant using trend analysis. For example, the recent IPCC special report on disasters and extremes concluded that this may take until mid-century for some variables ([IPCC, 2012a](#)), especially those associated with extreme rainfall and storm events. Ironically, if greenhouse-induced step changes do occur, non-linearity offers the potential to detect changes in extremes much faster than under gradual change, an area of potentially rich research. Observed changes in non-linear extremes where mean changes have been wholly or partially attributed to climate change are discussed in Section 3.3.

Cognitive values and ideals

Science is not value free as is widely claimed but is embedded in an ethical framework ([Carolan, 2006](#)). Commitments to factual claims and to value judgements co-evolve over time ([Kitcher, 2011](#)) and differ between disciplines. [Kitcher \(2011\)](#) proposes three levels that are operating in science:

1. The broad scheme of values that society holds;
2. A probative set of values – which problems are most important and which rules best validate/invalidate scientific conclusions?; and
3. The personal set of values that relates to an individual's knowledge goals (a cognitive set of values).

Levels one and two are most relevant to this study. Research into human-induced climate change is relevant to society-wide values, especially those at the international

scale. The probative values covering climate change cover the methods and rules from scientific disciplines ranging from physics and chemistry to the social sciences and humanities, but have been dominated by the natural sciences. To date, science communication has been largely ontological – what we know – rather than epistemological – why we believe that knowledge. The values applied within an epistemological setting are an important part of knowledge generation and communication, but have been largely overlooked

The study of climate change has been an overtly value-based exercise since Revelle and Suess began to examine the risks of rising greenhouse gases in the late 1950s ([Weart, 2008](#)). The IPCC was later established in 1988 as a hybrid organisation of scientists and policymakers to investigate those risks. The assessment frameworks and resulting discourses developed through the IPCC process are influenced by the norms and values of the research disciplines involved ([Hajer, 1993](#); [Siebenhüner, 2002](#); [Boykoff, 2007](#)).

The dominant role of the natural sciences, especially climatology, in the early stages of the IPCC means that the values within that broad group of scientists, such as rational decision-making, forecasting and a high regard for natural values, have predominated within the scientific discourse fostered by the IPCC.

The IPCC's emphasis on the analytic aspects of decision-making while paying insufficient regards to the way that people make decisions has come in for considerable criticism ([Pielke Jr and Sarewitz, 2005](#); [Sarewitz and Pielke Jr, 2007](#); [Hulme, 2009, 2011](#)). Although in recent years the social sciences have become much more prominent in adaptation research ([IPCC, 2007b](#)), the interface between the physical sciences on climate change and impacts and the socially-mediated process of implementing adaptation is still governed by traditional information transfer, although two-way communication and interdisciplinary collaboration are becoming more prominent ([Rayner and Malone, 1998](#); [Pelling, 2003](#); [Tribbia and Moser, 2008](#); [Sheate and Partidário, 2010](#); [Kuhlicke et al., 2011](#)).

Bottom-up methods build a broader range of values into an assessment at the outset, making stakeholder values a core part of an assessment. This avoids stakeholders having to adopt and translate an unfamiliar analytic framework according to their particular understanding. In this way, scientific knowledge can be incorporated into a broader planning or management framework – climate information needs are tailored into this process, rather than being imposed from outside. However, this task requires an understanding of how knowledge is generated and validated in both scientific and social contexts. This is an important task for boundary organisations that sit between the generation of science and the users of that knowledge.

Probative values consist of the rules for proof underpinning the use of a specific application. The two applications discussed in Section 2.5 were the STNM and forecasting. These are applications based on the idea of measurement, the desirability of balance and undesirability of imbalance that underpinned scientific rationalism. These ideas had their origin in the scientific enlightenment and have informed both science and economics ([Wise, 1993](#)). They allow coherence between different areas of knowledge. As Wise ([1993](#)) says *Measurements are not self-justifying. They employ particular sorts of instruments constructed for the purpose of attaching quantitative values to valued things.*

The signal to noise model has its origins in Gaussian statistics and earlier developments in the enlightenment, so has a long-standing status across science and economics ([Stigler, 1986](#)). The act of obtaining balance from uncertainty (variability)

and overcoming that uncertainty with predictability are rarely questioned values, and have become second nature in scientific practice. The following paragraphs are not intended to show that these aims are undesirable, but rather to show that the unquestioned application of such methods may lead to the biased application of knowledge.

Because of the success of the STNM in both D&A studies and its history and success in assessing long-term mean change for a range of variables, this model has become the main vehicle for communicating future climate change. Its ability in detection and attribution has been translated directly into projection, although no specific statistical proofs are available to assess the validity of a projection. Skill scores of climate models in observing current climate ([Suppiah et al., 2007](#)), and common experimental standards requiring certain standards for model structure ([Taylor et al., 2012](#)) are common methods, although various weighting methods have been tried ([Tebaldi et al., 2005](#); [Tebaldi and Knutti, 2007](#); [Watterson, 2008](#)).

Forecasting also has a long tradition in meteorology and is also seen as a primary goal for climatology. The probative component of forecasting is model skill, or the correlation of independent results from a given model experiment. If results are correlated in some way, then the model is said to have a measure of skill. There are many skill measures in the literature but if measured using the STNM or similar method, then model skill over multi-decadal scales will be interpreted as the correlation of mean change over those timescales.

The Global Framework for Climate Services is currently being developed by the WMO to provide a seamless delivery of climate information users and aims to “enable better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale” (World Climate Conference – 3).

While the Framework planning and roll out is strongly focused on meeting users’ requirements ([World Meteorological Organization, 2011](#)), its forecasting aspect is also strongly emphasised: *Weather and climate research are closely intertwined; progress in our understanding of climate processes and their numerical representation is common to both. Seamless prediction (on timescales from a few hours to centuries) needs to be further developed and extended to aspects across multiple disciplines relevant to climate processes* ([World Meteorological Organization, 2010](#)).

How values and ideals influence the measurement of forecasting skill and the subsequent presentation of scenarios and forecasts is critical. By favouring the STNM in measuring model skill, hypothesis 1, that emphasises a smoothly changing mean climate acts as a filter on the climate information that is passed on to users.

The quote from ([Solomon et al., 2010](#)): “*Long experience in weather and climate forecasting has shown that forecasts are of little utility without a priori assessment of forecast skill and reliability*”, empathises the role of climate forecasting on decadal scales. Although there is ample evidence that this assumption is quite appropriate for weather forecasting and for climate forecasting one season ahead, for climate forecasting over time periods of greater than one year there is little evidence for its utility. The available evidence of the success of such techniques is quite contradictory with stories of both success and failure ([Power et al., 2005](#); [Hulme et al., 2009](#); [Jones, 2010a](#)).

The probative values of science and risk are also different. The burden of proof for statistical methods attributing change to external drivers is 95% (a one in 20 chance

that a data sample is random) whereas for a risk to be worth assessing, scientific plausibility ($<<1\%$ event likelihood) is all that is required if the consequences of that event are of sufficient concern ([Jones, 2011](#)). Using the probative values of science to filter information to be used in a risk assessment, can bias the results of that assessment. To assess adaptation needs, all scientifically plausible cases need to be on the table, not just those selected by a particular form of rationalisation.

Therefore, the current values embedded in climate science, in the use of the STNM and forecasting techniques that generate and use gradual estimates of mean change, respectively, has a significant influence on adaptation policy and practice, especially because it is endorsed by practices auspiced by the IPCC and WMO. However, the next section shows that the strong reliance on such methods and the aim to meet user needs may not be consistent.

Theory and observations of rapid climate change

If anthropogenic climate change interacts with climate variability, the resulting changes will be inherently non-linear and that non-linearity will be coincident with regime changes in decadal variability. Below, we show that to be the case.

Figure 36 shows a variety of observed climate variables analysed using two methods: linear or non-linear (quadratic) line of best fit (a very simple method to extract the simple signal) and the step and trend method described in Jones (2012). All the step changes are statistically significant to the 5% level for the STARS test and the 1% level for the bivariate test. The results clearly show that temperature at the local, regional and global scale is non-linear, as are a number of other variables. In later sections we show that such changes will lead to non-linear economic impacts if analysed appropriately.

The greatest heat storage in the ocean-atmosphere system is in the ocean. Rates of heat diffusion in the ocean affect the rate of atmospheric warming ([Raper et al., 2001](#); [Raper et al., 2002](#)). The heat content of the top 700 m of ocean is shown in the lower right of the world map in Figure 36. The entire atmosphere holds as much heat as the top 3.2 m of the ocean ([Trenberth, 2002](#)). Model and observation-based studies also show that ocean temperature has a significant influence on atmospheric temperature at a range of timescales ([Fraedrich and Blender, 2003](#); [Dommenges, 2011](#); [Lambert et al., 2011](#)).

Greenhouse gases in the atmosphere act like a blanket trapping heat, warming the surface and cooling the upper atmosphere leading to a radiation deficit at the top of the atmosphere, so there are only two places where the bulk of that heat energy can go – into melting ice and into the ocean ([Trenberth et al., 2009](#)). The atmosphere cannot hold it and the land has a very low energy flux. In energy balance terms, the ocean carries about 90% of the extra heat from the past 50 years of greenhouse gas emissions ([Trenberth and Fasullo, 2010](#)). The ocean transports heat poleward and mixes heat into the deep ocean. [Meehl et al. \(2011\)](#) show that there is an increase in deep ocean mixing during warming hiatus periods where there is a slight decline in temperature. They associate these with La Niña-like patterns that have potential links to decadal oscillation mechanisms.

The latitudinal temperature from the 24°–44°S latitudinal band in Figure 36 shows the periodic nature of this process quite clearly. This area of the world is dominated by oceans, so surface air temperatures are highly correlated with sea surface temperature. Step changes through the 20th century show a slight cooling following by warming episodes that persist until the late century. Similar patterns can be seen in other ocean-dominated records.

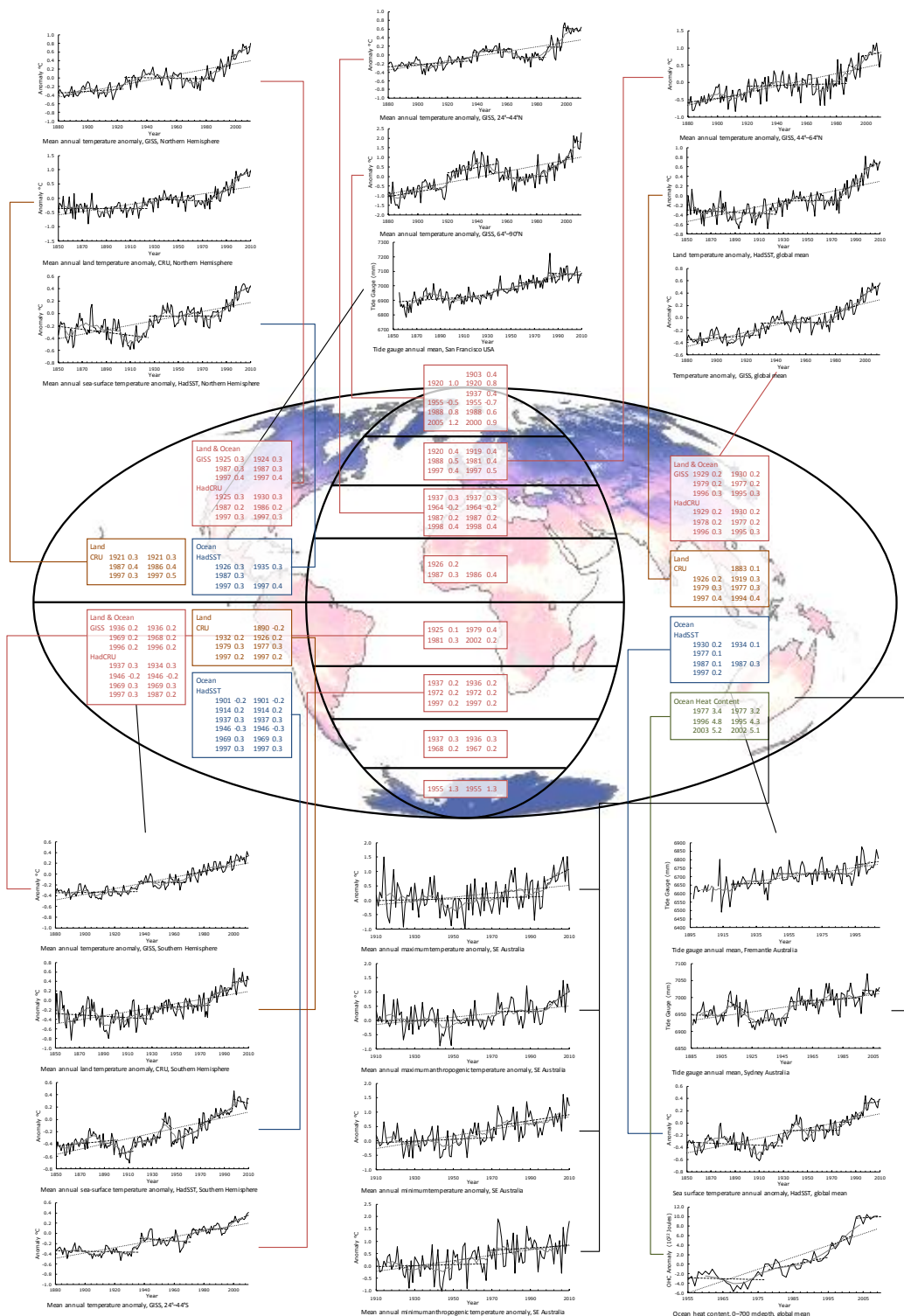


Figure 36. Selected local, regional and global climate variables covering air and sea surface temperature (Goddard Institute of Space Studies (GISS) data, Hadley/CRUt3 data, BoM and Jones (2012)), ocean heat content (NOAA NODC) and tide gauge records (PSMSL). Statistically significant step changes to the 1% and 5% level analysed with the bivariate test (left) and STARS test (right) are shown with year and size of change between periods. Method of analysis described in Jones (2012).

In the northern hemisphere, a cooling episode in the mid-20th century interrupted warming ([Ivanov and Evtimov, 2010](#)). Unpublished analyses of temperature change of several USA states using the method of removing natural variability from temperature records as carried out for SE Australia ([Jones, 2012](#)) suggests this cooling was due to natural variability. Using this method, climate was stationary for most of the 20th century and anthropogenic warming temperatures in continental USA did not begin until 1988.

The timing of many of the changes in trend in the literature often coincides with extreme events or changes in decadal variability ([Tomé and Miranda, 2004](#); [Menne, 2006](#); [Ivanov and Evtimov, 2010](#); [Ruggieri, 2013](#)). Notable dates for average temperature changes in Figure 36 are 1936, 1968 and 1997 in the southern hemisphere and 1920, 1988 and 1997 in the northern hemisphere; the dates 1946 and 1976 also occur in some latitudinal average records. These dates were selected using the STARS method trained with artificial data and the bivariate test using the filtering method described in [Jones \(2012\)](#).

The tests show a clearly accelerating number of shifts over the latter part of the record. Fewer shifts occur near the equator and more occur at higher latitudes. The most prominent of changes in temperature at the regional and global scale coincided with the 1997–98 ‘El Niño of the century’ ([Changnon and Bell, 2000](#); [Karl et al., 2000](#)). This registers as a 0.2–0.3°C step change within most of the GISS and Hadley data sets at the regional, hemispheric and global scale.

Ocean heat content shows shifts in 1976–77, 1995–96 and 2002–03, the first and second coinciding with regime shift observed in the Pacific ([Miller et al., 1994](#); [Hare and Mantua, 2000](#); [Gedalof and Smith, 2001](#); [Mantua and Hare, 2002](#); [Chavez et al., 2003](#)). Likewise, some of the northern hemisphere dates coincide with the North Atlantic Oscillation and/or the Atlantic Multidecadal Oscillation mechanism ([Wang et al., 2009](#); [Hurrell and Deser, 2010](#)). Closer to Australia, the Sydney and Fremantle tide gauge records show shifts in the early 1920s, mid 1940s and 1996–7, coinciding with known dates of changes in decadal regimes.

Analyses for Australia shows that temperature was fairly stationary until the late 1960s when a step change, mainly in minimum temperature occurred. Another step change in 1994 (sea surface temperatures) and 1997 (air temperature) mainly affected maximum temperature for the latter. Techniques removing the effect of natural climate variability based on the assumption of historical relationships remaining constant showed that the residual warming component of both maximum and minimum temperature showed step changes ([Jones, 2012](#)). An analysis of climate model output for south-eastern Australia shows climate models exhibit the same pattern of climate stationarity in the 20th century followed by step change warming initiated in minimum temperature or both minimum and maximum temperature. Often changes in minimum and maximum temperature are asynchronous, showing the influence of different environmental processes.

Although model output for regions other than south-eastern Australia have not been assessed, step changes in mean global warming from the suite of models investigated show that it's influenced by similar patterns of change as seen in Figure 36, so regional widespread non-linear behaviour can be assumed.

Dates of observed step changes in regional anthropogenic warming coincide with known regime changes linked to decadal climate variability. This evidence supports hypothesis 2: that anthropogenic climate change interacts with climate variability, instead of being independent of it. If decadal variability is seen as a regulating mechanism for poleward heat transport ([Schneider et al., 2002](#); [Visser et al., 2003](#);

[Zhang and McPhaden, 2006](#)), then decadal regime changes would be expected to produce non-linear warming in both the oceans and atmosphere under external forcing. In fact, given the low heat storage of the atmosphere, and non-linear behaviour of the ocean-atmosphere system on multiple scales, it is counter-intuitive to expect the atmosphere to warm gradually independently of these processes. Theory and observations therefore support hypothesis two whereas scientific values and methods support hypothesis one.

APPENDIX B: THE PROBLEM-SOLUTION ADAPTATION IMPLEMENTATION FRAMEWORK SUMMARY

Celeste Young



Figure 1: Problem solution framework for adaptation implementation

Introduction

This is a summary of the problem solution framework which has been designed to assist practitioners to understand better the process of adaptation and how it works at a practical level. It is the result of countless conversations with practitioners and researchers and also observations in relation to how projects are currently being managed. The idea of this framework is to give an over view of the process and to define the key phases, framing and tasks associated with it. It is also to define when the communication and the tools needed for the task change. Although adaptation is a process it is often articulated and actioned with the same framing and tools throughout the whole process even though it has two distinctly different phases. This can create disengagement and confusion about how to manage implementation and the associated risks.

If this was to be described through a health perspective, what some adaptation practitioners are doing is equivalent to a doctor who having diagnosed a cancer patient continues to focus on the cancer in a diagnostic way and talk about the problem of the cancer rather than the possible solutions to the cancer treatment needed. The same doctor would continue to use the tools available to diagnose the cancer to treat the cancer rather than find the most appropriate tool for that task or adapting the tool he already uses for the new purpose. However by using a single focus for two very different phases of a process that is essentially what is being done. Also no doctor would be allowed to undertake action without monitoring his patient's progress and assessing it at regular intervals.

The other reason for this framework is to encourage practitioners to consider looking at frameworks and systems that already in plain sight. Tools have been used for some time in the area of business innovation that can provide a way to manage uncertainty, introduce new technologies and behaviour change and to monitor unknown and evolving situations.

The phases

The framework is divided into two primary phases: the problem phase and the solution phase. These two phases both inform each other as elements of innovation will be involved in identifying the risk and elements of risk will be involved in the solution phase where innovative solutions are developed and implemented.

The problem phase

The key task of the problem phase is to identify and assess what the problem is. In the case of adaptation this involves assessing the impacts and associated risks of climate change. The framing for this phase is risk. The communication during this time is primarily concerned with identifying what the problem is, the collection of information regarding it and the creation of shared understandings as what the key problems are across a number of stakeholders. The tools using during this phase are risk based tools that allow for the collection of knowledge from a number of sources and the analysis of this information.

The solution phase

The key task of the solution phase is to respond to the assessment and decide what actions are to be undertaken, how they should be undertaken and by whom. The key framing for this phase is innovation. The communication through this phase is based on the solutions themselves and creating shared narratives and understandings in relation to this so that people are able to act with a common vision. The primary task during this phase is to assist the development, diffusion and adoption of the solution.

Key tasks

Because the risks in climate change are dynamic and constantly changing the process needs to be continuous in its nature in that once one task is complete the next task starts. Also one the process starts the current task will be informed by the previous task.

Task 1: Identification of the problem

Key questions:

- What is the problem?
- Who is affected by this problem?
- How are they affected by this problem?
- What is the priority?

This phase is where information and knowledge is collected from a number of different sources to identify the problem. The primary tools used are risk analysis tools and the primary communication is the translation of knowledge to assist with the identification

and understanding of the problem. This will require tools such as scenarios, different types of visual tools such as GIS mapping and 3 D representation of information.

Task 2: Assessment

Key questions:

- What is the priority problem?
- What is the most appropriate action to address this problem?
- Who should they be responsible for this?
- How will they be responsible for this?

The assessment phase is central to the process and during the cycle both the problem and solution inform what is assessed and the outcomes of the assessment (see Table 1).

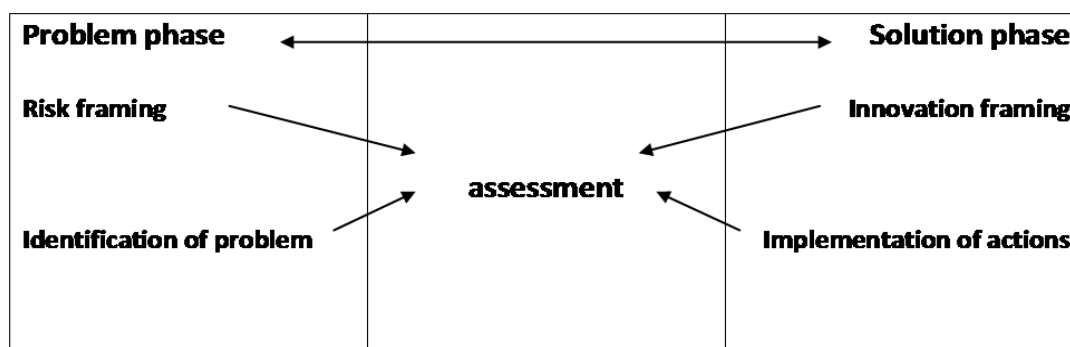


Table 1: Problem solution framework presented Department of Justice 2012

This task happens at two points of the cycle: Firstly when the findings of the problem phase are considered and then used to inform the decision as to what the best solution option and secondly after the implementation has been completed and the outcome of action is assessed.

Once the problem is identified and assessed this is the transition point from the *problem/ risk* focus to a *solution/innovation* focus. At the end of the implementation task where implementation is assessed the transition back is back to a *problem/ risk* focus.

Task 3: The implementation of actions

Key questions

- What are we doing?
- How is it working?
- What does this mean for the actions we are undertaking?

This is the active stage of the process where innovation based frameworks that are designed for uncertain outcomes and the different stages of implementation of new ideas and technologies are used. It also requires extensive collaboration between stakeholders and also multiple sources of communication that allow for information exchange and knowledge development between all the different stakeholders. It also requires constant monitoring and evaluation during this process and adjustments may be necessary in relation to this. Language used during this time is active and based around what the solution is and how it is progressing.

Acknowledgements: David McInnes, Pelagia Markongiankis, Chris Harvey, Judy Bush, Natalie Walker, Robyn Major, Greg Hunt, Ben Morris, Roger Jones, Ray Ison, Roni Beauchamp, Burke Renouf, Yvonne Lynch, Penny Mueller, Jurgен Schneider, Sebastian Carney, Rodney Keenan and all the practitioners from local and state government and industry who have shared their experience and observations.

REFERENCES

- Aaheim, A. and Aasen, M. (2008) What do we know about the economics of adaptation. *CEPS Policy Brief No. 150*, Centre for European Policy Studies, Brussels.
- ABARES (2011) Australian commodities: March quarter 2011, ABARES, Canberra, ACT.
- ABS (2012) Completing the Picture - Environmental Accounting in Practice. 4628.0.55.001, Australian Bureau of Statistics, Canberra ACT.
- Ackerman, F., DeCanio, S., Howarth, R. and Sheeran, K. (2009) Limitations of integrated assessment models of climate change. *Climatic Change*, **95**, 297-315.
- Ackerman, F. and Stanton, E.A. (2011) *Climate Economics: The State of the Art* Stockholm Environment Institute-U.S. Center, Somerville, MA.
- ACOSS (2013) Extreme weather, climate change and the community sector. *ACOSS Paper 197*, Australian Council of Social Services, Strawberry Hills, NSW.
- Adamson, D., Mallawaarachchi, T. and Quiggin, J. (2007) Climate change and climate uncertainty in the Murray-Darling Basin. *Murray Darling Program Working Paper: M07#2*, Risk and Sustainable Management Group, University of Queensland, Brisbane, Queensland.
- Adamson, D., Mallawaarachchi, T. and Quiggin, J. (2009) Declining inflows and more frequent droughts in the Murray–Darling Basin: climate change, impacts and adaptation*. *Australian Journal of Agricultural and Resource Economics*, **53**, 345-366.
- Adger, W., Agrawala, S., Mirza, M., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B. and Takahashi, K. (2007) Assessment of adaptation practices, options, constraints and capacity. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E.). Cambridge University Press, Cambridge, UK, pp. 717-743.
- Adger, W.N. (2000) Institutional adaptation to environmental risk under the transition in Vietnam. *Annals of the Association of American Geographers*, **90**, 738-758.
- Adger, W.N., Arnell, N.W. and Tompkins, E.L. (2005) Successful adaptation to climate change across scales. *Global Environmental Change*, **15**, 77-86.
- AECOM (2012) *Economic framework for analysis of climate change adaptation options: Framework specifications* Department of Climate Change and Energy Efficiency, Canberra.
- AGO (2006) Climate Change Impacts and Risk Management: A Guide for Business and Government, Australian Greenhouse Office, Canberra.
- Agrawala, S. and Fankhauser, S., eds. (2008) *Economic Aspects of Adaptation to Climate Change: Costs, benefits and policy instruments*. The Organisation for Economic Co-operation and Development, Paris.
- Agrawala, S., Kramer, A.M., Prudent-Richard, G. and Sainsbury, M. (2012) Incorporating Climate Change Impacts and Adaptation in Environmental Impact Assessments: Opportunities and Challenges. *OECD Environmental Working Paper No. 24*, OECD Publishing, Paris.

- Alcántara-Ayala, I. (2002) Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. *Geomorphology*, **47**, 107-124.
- Alley, R.B., Marotzke, J., Nordhaus, W., Overpeck, J., Peteet, D., Pielke, R., Pierrehumbert, R., Rhines, P., Stocker, T. and Talley, L. (2003) Abrupt climate change. *Science*, **299**, 2005-2010.
- Altopiedi, M. and Lavié, J.M. (2006) Narratives of change and collaboration: The role of professional and organizational identities in shaping school improvement plans. *Intervention Research*, **2**, 1-18.
- Arnell, N., Tompkins, E.L., Adger, N. and Delaney, K. (2005) Vulnerability to abrupt climate change in Europe. *Technical Report 34*, Tyndall Centre for Climate Change Research Southampton and East Anglia, UK.
- Arthur, W.B. (2009) *The nature of technology: what it is and how it evolves* Free Press, New York.
- Atkinson, G., Dietz, S., Helgeson, J., Hepburn, C.J. and Saelen, H. (2009) Siblings, Not Triplets: Social Preferences for Risk, Inequality and Time in Discounting Climate Change. *Economics: The Open-Access, Open-Assessment E-Journal*, **3**, 2009-2026.
- Atos (2012) Transforming a global leader, Atos, Bezons, France.
- Australian Government (2007) *Best Practice Regulation Handbook* Australian Government, Canberra, ACT.
- Australian Government (2010a) *Critical Infrastructure Resilience Strategy* Commonwealth of Australia, Canberra.
- Australian Government (2010b) *Best Practice Regulation Handbook* Australian Government, Canberra, ACT.
- Australian Greenhouse Office (1998) The National greenhouse strategy. Australian Greenhouse Office, Canberra, ACT, pp. v.
- Australian Innovation System (2011) *Australian Innovation System Report 2011* Department of Innovation, Industry, Science and Research, Canberra, ACT.
- Ayers, J.M. and Huq, S. (2009) Supporting adaptation to climate change: what role for official development assistance? *Development Policy Review*, **27**, 675-692.
- Bambrick, H., Dear, K., Woodruff, R., Hanigan, I. and McMichael, A. (2008) The impacts of climate change on three health outcomes: temperature-related mortality and hospitalisations, salmonellosis and other bacterial gastroenteritis, and population at risk from dengue *Garnaut Climate Change Review Technical Paper*, Garnaut Climate Change Review, Melbourne.
- Barkmann, J., Glenk, K., Keil, A., Leemhuis, C., Dietrich, N., Gerold, G. and Marggraf, R. (2008) Confronting unfamiliarity with ecosystem functions: The case for an ecosystem service approach to environmental valuation with stated preference methods. *Ecological Economics*, **65**, 48-62.
- Barnett, J. and O'Neill, S. (2010) Maladaptation. *Global Environmental Change*, **20**, 211-213.

- Bass, B. (2004) Measuring the Adaptation Deficit. In *Climate Change: Building the Adaptive Capacity* (eds Fenech, A., MacIver, D., Rong, R.B., Auld, H. and Ying, Y.). Meteorological Service of Canada, Environment Canada, Toronto, Ontario, Canada, pp. 34-36.
- Bateman, I.J., Day, B.H., Jones, A.P. and Jude, S. (2009) Reducing gain–loss asymmetry: a virtual reality choice experiment valuing land use change. *Journal of Environmental Economics and Management*, **58**, 106-118.
- Batterbury, S. (2010) Adaptive learning – a think-tank on preparedness for climate change adaptation in local and state planning in Victoria. In VCCCAR Think Tank Report. Victorian Centre for Climate Change Adaptation Research, Melbourne, pp. 19.
- Beck, U. (2000) Risk society revisited: theory, politics and research programmes. In *The risk society and beyond: critical issues for social theory* (eds Adam, B., Beck, U. and van Loon, J.). Sage, London, London.
- Bell, M.L., Hobbs, B.F. and Ellis, H. (2003) The use of multi-criteria decision-making methods in the integrated assessment of climate change: implications for IA practitioners. *Socio-Economic Planning Sciences*, **37**, 289-316.
- Bennett, A.F., Haslem, A., Cheal, D.C., Clarke, M.F., Jones, R.N., Koehn, J.D., Lake, P.S., Lumsden, L.F., Lunt, I.D., Mackey, B.G., Nally, R.M., Menkhorst, P.W., New, T.R., Newell, G.R., O'Hara, T., Quinn, G.P., Radford, J.Q., Robinson, D., Watson, J.E.M. and Yen, A.L. (2009) Ecological processes: A key element in strategies for nature conservation. *Ecological Management & Restoration*, **10**, 192-199.
- Beven, K. (2002) Towards a coherent philosophy for modelling the environment. *Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, **458**, 2465-2484.
- Blong, R.J. (2005) Natural Hazards Risk Assessment—An Australian Perspective. *Benfield Hazards Research Centre Issues Paper No. 4*, University College London, London, UK.
- Boje, D.M., Oswick, C. and Ford, J.D. (2004) Introduction to Special Topic Forum: Language and Organization: The Doing of Discourse. *The Academy of Management Review*, **29**, 571-577.
- Boykoff, M.T. (2007) From convergence to contention: United States mass media representations of anthropogenic climate change science. *Transactions of the Institute of British Geographers*, **32**, 477-489.
- Brooks, N., Neil Adger, W. and Mick Kelly, P. (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change*, **15**, 151-163.
- Brown, C., Werick, W., Leger, W. and Fay, D. (2011) A decision analytic approach to managing climate risks – Application to the Upper Great Lakes. *JAWRA Journal of the American Water Resources Association*, **47**, 524-534.
- Bücher, A. and Dessens, J. (1991) Secular trend of surface temperature at an elevated observatory in the Pyrenees. *Journal of Climate*, **4**, 859-868.
- Burby, R.J. (2006) Hurricane Katrina and the paradoxes of government policy: bringing about wise governmental decisions for Hazardous areas. *Annals of the American Academy of Political and Social Science*, **604**, 171-191.

- Burns, W.J., Slovic, P., Kasperson, R.E., Kasperson, J.X., Renn, O. and Emani, S. (1993) Incorporating Structural Models into Research on the Social Amplification of Risk: Implications for Theory Construction and Decision Making. *Risk Analysis*, **13**, 611-623.
- Burton, I., Kates, R.W. and White, G.F. (1993) *The Environment As Hazard* Guilford Press, New York, NY, USA.
- Burton, I. (2004) Climate Change and the Adaptation Deficit. In *Climate Change: Building the Adaptive Capacity* (eds Fenech, A., MacIver, D., Rong, R.B., Auld, H. and Ying, Y.). Meteorological Service of Canada, Environment Canada, Toronto, Ontario, Canada, pp. 25-33.
- Burton, I. and May, E. (2004) The adaptation deficit in water resources management. *IDS Bulletin*, **35**, 31-37.
- Carolan, M.S. (2006) Scientific knowledge and environmental policy: why science needs values. *Environmental Sciences*, **3**, 229-237.
- Carter, T.R., Parry, M.L., Harasawa, H. and Nishioka, S. (1994) *IPCC technical guidelines for assessing climate change impacts and adaptations* Center for Global Environmental Research and National Institute for Environmental Studies, London and Japan.
- Carter, T.R., Jones, R.N., Lu, X., Bhadwal, S., Conde, C., Mearns, L.O., O'Neill, B.C., Rounsevell, M.D.A. and Zurek, M.B. (2007) New Assessment Methods and the Characterisation of Future Conditions. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E.). Cambridge University Press, Cambridge, UK, pp. 133-171.
- CCS (2011) Centre for Climate Strategies Adaptation Guidebook: Comprehensive Climate Action. The Centre for Climate Strategies, Washington, DC, USA, pp. 124.
- Changnon, S.A. and Bell, G.D. (2000) *El Niño, 1997-1998: The Climate Event of the Century* Oxford University Press.
- Chavez, F.P., Ryan, J., Lluch-Cota, S.E. and Niquen C., M. (2003) From Anchovies to Sardines and Back: Multidecadal Change in the Pacific Ocean. *Science*, **299**, 217-221.
- Chiew, F., Teng, J., Kirono, D., Frost, A., Bathols, J., Vaze, J., Viney, N., Young, W., Hennessy, K. and Cai, W. (2008) *Climate data for hydrologic scenario modelling across the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project* CSIRO, Australia. 35pp.
- Chiew, F.H.S., Teng, J., Vaze, J., Post, D.A., Perraud, J.M., Kirono, D.G.C. and Viney, N.R. (2009) Estimating climate change impact on runoff across southeast Australia: Method, results, and implications of the modeling method. *Water Resources Research*, **45**, WR007338.
- Christidis, N., Stott, P., Zwiers, F., Shiogama, H. and Nozawa, T. (2011) The contribution of anthropogenic forcings to regional changes in temperature during the last decade. *Climate Dynamics*, 1-16.
- COAG (2004) *Natural Disasters in Australia: Reforming mitigation, relief and recovery arrangements* Council of Australian Governments, Canberra, ACT.

- COAG (2007) National Climate Change Adaptation Framework.
- COAG (2011a) *National strategy for disaster resilience: building our nation's resilience to disasters* Council of Australian Governments, Canberra, ACT.
- COAG (2011b) Attachment C to Communiqué, 13 February 2011 - More Effective Ministerial Council System. *Communiqué - 13 February 2011*, Council of Australian Governments, Canberra ACT.
- Collins, M. (2002) Climate predictability on interannual to decadal time scales: the initial value problem. *Climate Dynamics*, **19**, 671-692.
- Collins, M. and Allen, M.R. (2002) Assessing the Relative Roles of Initial and Boundary Conditions in Interannual to Decadal Climate Predictability. *Journal of Climate*, **15**, 3104-3109.
- Collins, M., Fricker, T. and Hermanson, L. (2011) From observations to forecasts – Part 9: what is decadal forecasting? *Weather*, **66**, 160-164.
- Comrie, N. (2011) *Review Of The 2010–11 Flood Warnings & Response* Victorian Government, Melbourne.
- Corti, S., Molteni, F. and Palmer, T.N. (1999) Signature of recent climate change in frequencies of natural atmospheric circulation regimes. *Nature*, **398**, 799-802.
- Craig, R. (2010) 'Stationarity is Dead'-Long Live Transformation: Five Principles for Climate Change Adaptation Law. *Harvard Environmental Law Review*, **34**, 9-75.
- CSIRO and BoM, eds. (2007) *Climate Change in Australia*. CSIRO, Melbourne, pp 148.
- DCC (2009) *Climate Change Risks to Australia's Coasts, A First Pass National Assessment* Department of Climate Change, Canberra, ACT.
- De'ath, G., Fabricius, K. and Authority, G.B.R.M.P. (2008) *Water quality of the Great Barrier Reef: distributions, effects on reef biota and trigger values for the protection of ecosystem health* Great Barrier Reef Marine Park Authority.
- De Tarde, G. (1903) *The laws of imitation* Henry, Holt and Company, New York, USA.
- Department of Climate Change and Energy Efficiency (2010) Climate Change Adaptation Program, Vol. 2013. Department of Climate Change and Energy Efficiency, Canberra ACT.
- Department of Finance and Deregulation (2008) Best Practice Regulation Guidance Note: Value of Statistical Life. Office of Best Practise Regulation, Australian Government, Canberra.
- Department of Health and Ageing and enHealth Council (2003) *Guidelines for Economic Evaluation of Environmental Health Planning and Assessment. Volume 1 — The Guidelines* Commonwealth of Australia, Canberra.
- Department of Treasury and Finance Tasmania (1996) Project Initiation Process. Department of Treasury and Finance Tasmania, Hobart.
- Dessai, S. and Hulme, M. (2007) Assessing the robustness of adaptation decisions to climate change uncertainties: A case study on water resources management in the East of England. *Global Environmental Change*, **17**, 59-72.

- Dessai, S. and van der Sluijs, J.P. (2007) Uncertainty and climate change adaptation : a scoping study. *NWS-E*, Copernicus Institute for Sustainable Development and Innovation, Department of Science Technology and Society, Utrecht.
- Dessai, S., Hulme, M., Lempert, R.J. and Pielke Jr, R. (2009) Climate prediction: a limit to adaptation? In *Adapting to climate change: Thresholds, values, governance* (eds Adger, W.N., Lorenzoni, I. and O'Brien, K.L.). Cambridge University Press, Cambridge, pp. 49-57.
- Dobes, L. and Bennett, J. (2009) Multi-Criteria Analysis: "Good Enough" for Government Work? *Agenda*, **16**, 7-29.
- Dobes, L. (2012) Adaptation to Climate Change: Formulating Policy under Uncertainty. *CCEP Working Paper 1201*, Centre for Climate Economics and Policy, Crawford School of Public Policy, Canberra.
- Dommenget, D. (2011) Comments on "The Relationship between Land–Ocean Surface Temperature Contrast and Radiative Forcing". *Journal of Climate*, **25**, 3437-3440.
- Doria, M.d.F., Boyd, E., Tompkins, E.L. and Adger, W.N. (2009) Using expert elicitation to define successful adaptation to climate change. *Environmental Science & Policy*, **12**, 810-819.
- Dovers, S. (2009) Normalizing adaptation. *Global Environmental Change*, **19**, 4-6.
- Downing, T., Ringius, L., Hulme, M. and Waughray, D. (1997) Adapting to Climate Change in Africa. *Mitigation and Adaptation Strategies for Global Change*, **2**, 19-44.
- Drucker, P.F. (2011) *The Five Most Important Questions You Will Ever Ask About Your Organization* John Wiley & Sons.
- Ebbesmeyer, C.C., Cayan, D.R., McLain, D.R., Nichols, F.H., Peterson, D.H. and Redmond, K.T. (1991) 1976 step in the Pacific climate: forty environmental changes between 1968-1975 and 1977-1984. In *Proceedings of the Seventh annual Pacific Climate (PACCLIM) Workshop* (eds. Betancourt, J.L. and Tharp, V.L.), Vol. Technical Report 26. California Department of Water Resources. Interagency Ecology Studies Program, Asilomar, California, April, 1990, pp. 115-126.
- Edwards, P.N. (1999) Global climate science, uncertainty and politics: Data-laden models, model-filtered data. *Science as Culture*, **8**, 437 - 472.
- Emergency Management Australia (1993) *Commonwealth counter disaster concepts and principles*, 2nd edn. Emergency Management Australia, Parkes, ACT.
- Erskine, W.D. and Warner, R.F. (1998) Further assessment of flood- and drought-dominated regimes in south-eastern Australia. *Australian Geographer*, **29**, 257 - 261.
- Evans, J. (2009) 21st century climate change in the Middle East. *Climatic Change*, **92**, 417-432.
- Farber, S.C., Costanza, R. and Wilson, M.A. (2002) Economic and ecological concepts for valuing ecosystem services. *Ecological Economics*, **41**, 375-392.

- Fenton, M., Kelly, G., Vella, K. and Innes, J. (2007) Climate change and Great Barrier Reef: industries and communities. In *Climate change and the Great Barrier Reef: a vulnerability assessment* (eds Johnson, J.E. and Marshall, P.A.). Great Barrier Reef Marine Park Authority and the Australian Greenhouse Office, Townsville, Queensland, pp. 745-771.
- Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S. and Walker, B. (2002) Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations. *AMBIO: A Journal of the Human Environment*, **31**, 437-440.
- Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T. and Rockstrom, J. (2010) Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and Society*, **14**, 20.
- Fraedrich, K. and Blender, R. (2003) Scaling of Atmosphere and Ocean Temperature Correlations in Observations and Climate Models. *Physical Review Letters*, **90**, 108501.
- Fredriksen, J., Fredriksen, C., Osbrough, S. and Sisson, J. (2010) Causes of changing Southern Hemisphere weather systems. In *Managing Climate Change: Papers from the Greenhouse 2009 Conference* (eds Jubb, I., Holper, P. and Cai, W.J.). CSIRO Publishing, Melbourne, pp. 85-98.
- Freudenberg, W.R., Gramling, R.B., Laska, S.B. and Erikson, K.T. (2009) *Catastrophe in the Making: The Engineering of Katrina and the Disasters of Tomorrow* Island Press/Shearwater Books, Washington, DC.
- Füssel, H.M. (2010) Modeling impacts and adaptation in global IAMs. *Wiley Interdisciplinary Reviews: Climate Change*, **1**, 288-303.
- Gagnon-Lebrun, F. and Agrawala, S. (2006) Progress on Adaptation to Climate Change in Developed Countries: An Analysis of Broad Trends. *ENV/EPOC/GSP(2006)1/FINAL* OECD, Paris.
- Gan, T.Y. (1995) Trends in air temperature and precipitation for Canada and north-eastern USA. *International Journal of Climatology*, **15**, 1115-1134.
- Garnaut, R. (2008) *The Garnaut climate change review: final report* Cambridge University Press, Port Melbourne, Vic.
- Gedalof, Z. and Smith, D.J. (2001) Interdecadal climate variability and regime-scale shifts in Pacific North America. *Geophysical Research Letters*, **28**, 1515-1518.
- Gephart Jr, R.P. (1991) Succession Sensemaking and Organizational Change: A Story of a Deviant College President. *Journal of Organizational Change Management*, **4**, 35-44.
- Gregory, W.L. and Duran, A. (2001) Scenarios and Acceptance of Forecasts. In *Principles of forecasting: a handbook for researchers and practitioners* (ed. Armstrong, J.S.). Springer, Berlin, pp. 519-541.
- Groves, D.G., Davis, M., Wilkinson, R. and Lempert, R. (2008) Planning for Climate Change in the Inland Empire: Southern California. *Water Resources IMPACT*, **10**, 14-17.
- Gurran, N., Norman, B., Gilbert, C. and Hamin, E. (2011) Planning for climate change adaptation in Coastal Australia: State of practice. *Report No. 4 for the National Sea Change Taskforce*, Faculty of Architecture, Design and Planning, University of Sydney, Sydney, NSW.

- Hacking, I. (1993) Working in a new world: The taxonomic solution. In *World changes: Thomas Kuhn and the nature of science* (ed. Horwich, P.). MIT Press, Cambridge, MA.
- Hajer, M. (1993) Discourse coalitions and the institutionalization of practice: the case of acid rain in Britain. In *The argumentative turn in policy analysis and planning* (eds Fischer, F. and Forester, J.). Duke University Press, Durham NC, pp. 43-76.
- Hallegatte, S. (2009) Strategies to adapt to an uncertain climate change. *Global Environmental Change*, **19**, 240-247.
- Hallegatte, S. (2011) Uncertainties in the Cost-Benefit Analysis of Adaptation Measures, and Consequences for Decision Making. In *Climate* (eds Linkov, I. and Bridges, T.S.). Springer Netherlands, pp. 169-192.
- Hallegatte, S., Lecocq, F. and de Perthuis, C. (2011) Designing Climate Change Adaptation Policies: An Economic Framework. *Policy Research Working Paper 5568*, The World Bank, Washington, DC.
- Hallegatte, S., Shah, A., Lempert, R., Brown, C. and Gill, S. (2012) Investment decision making under deep uncertainty -- application to climate change. *Policy Research Working Paper Series No. 6193*, The World Bank.
- Handmer, J., Honda, Y., Kundzewicz, Z.W., Arnell, N., Benito, G., Hatfield, J., Mohamed, I.F., Peduzzi, P., Wu, S., Sherstyukov, B., Takahashi, K. and Yan, Z. (2012a) Changes in Impacts of Climate Extremes: Human Systems and Ecosystems. In *IPCC SREX*. Cambridge University Press, Cambridge and New York.
- Handmer, J., Honda, Y., Kundzewicz, Z.W., Arnell, N., Benito, G., Hatfield, J., Mohamed, I.F., Peduzzi, P., Wu, S., Sherstyukov, B., Takahashi, K. and Yan, Z. (2012b) Changes in Impacts of Climate Extremes: Human Systems and Ecosystems. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (eds Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M. and Midgley, P.M.). Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 231-290.
- Handmer, J. and Dovers, S. (2013) *Handbook of Disaster Policies and Institutions*, 2 edn. Routledge, London and New York.
- Hare, S.R. and Mantua, N.J. (2000) Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progress In Oceanography*, **47**, 103-145.
- Harrison, M. (2010) Valuing the Future: the social discount rate in cost-benefit analysis. *Visiting Researcher Paper*, Productivity Commission, Canberra.
- Hartley, J., Thomas, M. and Mushtaq, D. (2011) A Regional General Equilibrium Analysis of the 2011 Queensland Flood Disaster. In *Proceedings of the 41st Australian Conference of Economists, The Future of Economics: Research, Policy and Relevance* (ed. by Doughney, J. and Hoa, T.V.). Victoria University, Melbourne, Victoria University, Melbourne, pp. MS91.
- Hasselmann, K. (1979) On the signal-to-noise problem in atmospheric response studies. In *Meteorology of Tropical Oceans* (ed. Shaw, D.B.). Royal Meteorological Society, London, UK, pp. 251-259.

- Hasselmann, K. (2002) Is Climate Predictable? In *The Science of Disasters: Climate Disruptions, Heart Attacks, and Market Crashes* (eds Bunde, A., Kropp, J. and Schellnhuber, H.J.). Springer, Berlin Heidelberg, pp. 141-188.
- Hatton MacDonald, D., Crossman, N.D., Mahmoudi, P., Taylor, L.O., Summers, D.M. and Boxall, P.C. (2010) The value of public and private green spaces under water restrictions. *Landscape and Urban Planning*, **95**, 192-200.
- Hawkins, E. and Sutton, R. (2011) The potential to narrow uncertainty in projections of regional precipitation change. *Climate Dynamics*, **37**, 407-418.
- Hegerl, G.C., Zwiers, F.W., Braconnot, P., Gillett, N.P., Luo, Y., Orsini, J.A.M., Nicholls, N., Penner, J.E. and Stott, P.A. (2007) Understanding and Attributing Climate Change. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., pp. 663-745.
- Hegerl, G.C., Hoegh-Guldberg, O., Casassa, G., Hoerling, M.P., Kovats, R.S., Parmesan, C., Pierce, D.W. and Stott, P.A. (2010) Good practice guidance paper on detection and attribution related to anthropogenic climate change. In *Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Detection and Attribution of Anthropogenic Climate Change* (eds Stocker, T.F., Field, C.B., Qin, D., Barros, V., Plattner, G.-K., Tignor, M., Midgley, P.M. and Ebi, K.L.). IPCC Working Group I Technical Support Unit University of Bern, Bern, Switzerland, pp. 8.
- Hennessy, K., Fitzharris, B., Bates, B.C., Harvey, N., Howden, S.M., Hughes, L., Salinger, J. and Warrick, R. (2007) Australia and New Zealand. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Parry, M.L., Canziani, O.F., Palutikof, J.P., Linden, P.J.v.d. and Hanson, C.E.). Cambridge University Press, Cambridge, UK, pp. 507-540.
- Heuson, C., Gawel, E., Gebhardt, O., Hansjürgens, B., Lehmann, P., Meyer, V. and Schwarze, R. (2012) Fundamental Questions on the Economics of Climate Adaptation, Outlines of a New Research Programme. *Report 05/2012*, Helmholtz Centre for Environmental Research, UFZ Department of Economics, Leipzig, Germany.
- Hewitt, K. and Burton, I. (1971) *The Hazardousness of a Place: A Regional Ecology of Damaging Events* University of Toronto, Toronto.
- Hippel, E.v. (1988) *The sources of innovation* Oxford University Press, New York.
- HM Treasury (2003) *The Green Book: Appraisal and Evaluation in Central Government* Treasury Guidance, London.
- Hughes, L. and McMichael, T. (2011) *The Critical Decade: Climate Change and Health* Climate Commission Secretariat (Department of Climate Change and Energy Efficiency), Canberra.
- Hulme, M. and Mearns, L. (2001) Climate Scenario Development. In *Climate Change 2001: The Scientific Basis 2001* (eds Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., Van Der Linden, P.J. and Xiaosu, D.). Cambridge University Press, Cambridge and New York, pp. 739-768.

- Hulme, M. (2003) Abrupt climate change: can society cope? *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, **361**, 2001-2021.
- Hulme, M. (2008) The conquering of climate: discourses of fear and their dissolution. *The Geographical Journal*, **174**, 5-16.
- Hulme, M. (2009) *Why we disagree about climate change: understanding controversy, inaction and opportunity* Cambridge University Press, Cambridge and New York.
- Hulme, M., Pielke, R. and Dessai, S. (2009) Keeping prediction in perspective. *Nature Reports Climate Change*, 126-127.
- Hulme, M. (2011) Reducing the Future to Climate: A Story of Climate Determinism and Reductionism. *Osiris*, **26**, 245-266.
- Huq, S. and Reid, H. (2004) Mainstreaming adaptation in development. *IDS Bulletin*, **35**, 15-21.
- Hurrell, J.W., Delworth, T.L., Danabasoglu, G., Drange, H., Drinkwater, K., Griffies, S., Holbrook, N., Kirtman, B., Keenlyside, N., Latif, M., Marotzke, J., Murphy, J., Meehl, G.A., Palmer, T., Pohlmann, H., Rosati, T., Seager, R., Smith, D., Sutton, R., Timmermann, A., Trenberth, K.E., Tribbia, J. and Visbeck, M. (2009) Decadal climate prediction: opportunities and challenges. In *OceanObs'09: Sustained Ocean Observations and Information for Society Conference* (eds. Hall, J., Harrison, D.E. and Stammer, D.), Vol. 2. ESA Publication WPP-306, Venice, Italy, pp. 23.
- Hurrell, J.W. and Deser, C. (2010) North Atlantic climate variability: The role of the North Atlantic Oscillation. *Journal of Marine Systems*, **79**, 231-244.
- Infrastructure Australia (2008) *Outline of Infrastructure Australia's Prioritisation Methodology* Government of Australia Canberra.
- IOCI (Indian Ocean Climate Initiative) (2002) *Climate variability and change in south west Western Australia* Indian Ocean Climate Initiative Panel, Perth.
- IPCC-TGICA (1999) Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment: Version 1, Task Group on Scenarios for Climate Impact Assessment, Geneva.
- IPCC-TGICA (2007) General Guidelines on the use of Scenario Data for Climate Impact and Adaptation Assessment: Version 2, Task Group on Scenarios for Climate Impact Assessment, Geneva.
- IPCC, ed. (2007a) *Climate Change 2007: Mitigation. Contribution of Working Group III to the Intergovernmental Panel on Climate Change Fourth Assessment Report*. Cambridge University Press, Cambridge.
- IPCC (2007b) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, U.K.
- IPCC (2007c) *Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge.

- IPCC (2012a) Summary for Policymakers. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (eds Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M. and Midgley, P.M.). Cambridge University Press, Cambridge, UK and New York, USA, pp. 1-19.
- IPCC (2012b) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, USA.
- ISO (2009) ISO 31000:2009 Risk management - Principles and guidelines. International Organisation for Standardisation, Geneva.
- Ivanov, M.A. and Evtimov, S.N. (2010) 1963: The break point of the Northern Hemisphere temperature trend during the twentieth century. *International Journal of Climatology*, **30**, 1738-1746.
- Jasanoff, S. (1996) Beyond epistemology: relativism and engagement in the politics of science. *Social Studies of Science*, **26**, 393-418.
- Jasanoff, S. (2010) A New Climate for Society. *Theory, Culture & Society*, **27**, 233-253.
- Johnson, J.E. and Marshall, P.A., eds. (2007) *Climate change and the Great Barrier Reef: a vulnerability assessment*. Great Barrier Reef Marine Park Authority and the Australian Greenhouse Office, Townsville, Queensland, pp 818.
- Jones, A., Allen, I., Nick Silver, Cameron, C., Howarth, C. and Caldecott, B. (2013) Resource constraints: sharing a finite world, The Institute and Faculty of Actuaries, London, UK.
- Jones, R. (2004a) Incorporating agency into climate change risk assessments - An editorial comment. *Climatic Change*, **67**, 13-36.
- Jones, R. and Mearns, L. (2005) Assessing future climate risks. In *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures* (eds Lim, B., Spanger-Siegfried, E., Burton, I., Malone, E. and Huq, S.). Cambridge University Press, Cambridge and New York, , pp. 119-143.
- Jones, R., Dettmann, P., Park, G., Rogers, M. and White, T. (2007) The relationship between adaptation and mitigation in managing climate change risks: a regional response from North Central Victoria, Australia. *Mitigation and Adaptation Strategies for Global Change*, **12**, 685-712.
- Jones, R. and Webb, L. (2008) Regional and Sectoral Vulnerability to Climate Change in Victoria. Report prepared for Victorian Department of Treasury and Finance, CSIRO Climate Adaptation Flagship, Melbourne.
- Jones, R. (2010a) A risk management approach to climate change adaptation. In *Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives* (eds Nottage, R.A.C., Wratt, D.S., Bornman, J.F. and Jones, K.). New Zealand Climate Change Centre, Wellington, New Zealand, pp. 10-25.
- Jones, R. (2011) The latest iteration of IPCC uncertainty guidance—an author perspective. *Climatic Change*, **108**, 733-743.

- Jones, R.N. (2001) An environmental risk assessment/management framework for climate change impact assessments. *Natural Hazards*, **23**, 197-230.
- Jones, R.N., McMahon, T.A. and Bowler, J.M. (2001) Modelling historical lake levels and recent climate change at three closed lakes, Western Victoria, Australia (c.1840-1990). *Journal of Hydrology*, **246**, 159-180.
- Jones, R.N. and Page, C.M. (2001) Assessing the risk of climate change on the water resources of the Macquarie River Catchment. In *Integrating Models for Natural Resources Management across Disciplines, Issues and Scales (Part 2)* (eds Ghassemi, F., Whetton, P., Little, R. and Littleboy, M.). Modelling and Simulation Society of Australia and New Zealand, Canberra, pp. 673-678.
- Jones, R.N. (2004b) Managing Climate Change Risks. In *The Benefits of Climate Change Policies: Analytical and Framework Issues* (eds Agrawal, S. and Corfee-Morlot, J.). OECD, Paris, pp. 249-298.
- Jones, R.N. and Preston, B.L. (2006) Climate change impacts, risk and the benefits of mitigation. CSIRO, Canberra, pp. 97 p.
- Jones, R.N. (2010b) North central Victorian climate: past, present and future. *Proceedings of the Royal Society of Victoria*, **122**, 147-160.
- Jones, R.N. and Preston, B.L. (2011) Adaptation and risk management *WIREs Climate Change*, **2**, 296-308.
- Jones, R.N. (2012) Detecting and attributing nonlinear anthropogenic regional warming in southeastern Australia. *Journal of Geophysical Research*, **117**, D04105.
- Jotzo, F. (2010) Prerequisites and limits for economic modelling of climate change impacts and adaptation. *Research Report No. 55*, Environmental Economics Research Hub, Australian National University, Canberra.
- Kahneman, D. and Tversky, A. (1979) Prospect theory: An analysis of decision under risk. *Econometrica*, **47**, 263-292.
- Kahneman, D. (2003) Maps of bounded rationality: psychology for behavioral economics. *The American Economic Review*, **93**, 1449-1475.
- Kahneman, D. (2011) *Thinking, fast and slow*, 1st edn. Farrar, Straus and Giroux, New York.
- Kandlikar, M., Risbey, J. and Dessai, S. (2005) Representing and communicating deep uncertainty in climate-change assessments. *Comptes Rendus Geoscience*, **337**, 443-455.
- Karl, T.R., Knight, R.W. and Baker, B. (2000) The record breaking global temperatures of 1997 and 1998: Evidence for an increase in the rate of global warming? *Geophysical Research Letters*, **27**, 719-722.
- Kasperson, R.E. (1992) The Social Amplification of Risk: Progress in Developing an Integrative Framework in Social Theories of Risk. In *Social Theories of Risk* (eds Krinsky, S. and Golding, D.). Praeger, Westport, CT, USA, pp. 53-178.
- Kasprzyk, J.R., Nataraj, S., Reed, P.M. and Lempert, R.J. (2013) Many objective robust decision making for complex environmental systems undergoing change. *Environmental Modelling & Software*, **42**, 55-71.

- Katz, R. and Brown, B. (1992) Extreme events in a changing climate: Variability is more important than averages. *Climatic Change*, **21**, 289-302.
- Keating, A. and Handmer, J. (2011a) The cost of disasters in Australia and Victoria: No straightforward answers. *VCCCAR Project: Framing Adaptation in the Victorian Context, Working Paper 3*, Victorian Centre for Climate Change Adaptation Research, Melbourne.
- Keating, A. and Handmer, J. (2011b) Options for assessing the cost of climate change for adaptation policy in Victoria. *VCCCAR Project: Framing Adaptation in the Victorian Context, Working Paper 2*, Victorian Centre for Climate Change Adaptation Research, Melbourne.
- Keating, A. (2013) Food Security in Australia: The Logistics of Vulnerability. In *Food Security in Australia: Challenges and Prospects for the Future* (eds Farmar-Bowers, Q., Higgins, V. and Millar, J.). Springer, New York and Heidelberg, pp. 21-34.
- Keating, A. and Handmer, J. (2013) Future potential losses from extremes under climate change: the case of Victoria, Australia. *VCCCAR Project: Framing Adaptation in the Victorian Context, Working Paper* Victorian Centre for Climate Change Adaptation Research, Melbourne.
- Keller, K., Bolker, B.M. and Bradford, D.F. (2004) Uncertain climate thresholds and optimal economic growth. *Journal of Environmental Economics and Management*, **48**, 723-741.
- Kenny, G.J., Warrick, R.A., Campbell, B.D., Sims, G.C., Camilleri, M., Jamieson, P.D., Mitchell, N.D., McPherson, H.G. and Salinger, M.J. (2000) Investigating climate change impacts and thresholds: an application of the CLIMACTS integrated assessment model for New Zealand agriculture. *Climatic Change*, **46**, 91-113.
- Kirono, D. and Jones, R. (2007) A bivariate test for detecting inhomogeneities in pan evaporation time series. *Australian Meteorological Magazine*, **56**, 93-103.
- Kiser, L.L. and Ostrom, E. (1982) The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Approaches. In *In Strategies of Political Inquiry* (ed. Ostrom, E.). Sage, Beverly Hills, CA, pp. 179-222.
- Kitcher, P. (2011) *Science, truth, and democracy* Oxford University Press, Oxford ; New York.
- Kowalski, K., Stagl, S., Madlener, R. and Omann, I. (2009) Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. *European Journal of Operational Research*, **197**, 1063-1074.
- Kuhlicke, C., Steinführer, A., Begg, C., Bianchizza, C., Bründl, M., Buchecker, M., De Marchi, B., Di Masso Tarditti, M., Höppner, C., Komac, B., Lemkow, L., Luther, J., McCarthy, S., Pellizzoni, L., Renn, O., Scolobig, A., Supramaniam, M., Tapsell, S., Wachinger, G., Walker, G., Whittle, R., Zorn, M. and Faulkner, H. (2011) Perspectives on social capacity building for natural hazards: outlining an emerging field of research and practice in Europe. *Environmental Science & Policy*, **14**, 804-814.
- Kuhn, T.S. (1962) *The structure of scientific revolutions* University of Chicago Press, [Chicago].
- Lambert, F.H., Webb, M.J. and Joshi, M.M. (2011) The Relationship between Land–Ocean Surface Temperature Contrast and Radiative Forcing. *Journal of Climate*, **24**, 3239-3256.

- László, J. and Ehmann, B. (2012) Narrative social psychology. In *EASP Small Group Meeting on Social Cognition and Communication* (eds. Laszlo, J., Forgas, J. and Vincze, O.), 9 - 12th July, 2012, Pecs, Hungary, pp. 38.
- Laudan, L. (1984) *Science and values : the aims of science and their role in scientific debate* University of California Press, Berkeley.
- Lempert, R.J. and Collins, M.T. (2007) Managing the risk of uncertain threshold responses: Comparison of robust, optimum, and precautionary approaches. *Risk Analysis*, **27**, 1009-1026.
- Lempert, R.J. and Kalra, N. (2011) Managing Climate Risks in Developing Countries with Robust Decision Making. *World Resources Report*, World Resources Institute, Washington, D.C.
- Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S. and Schellnhuber, H.J. (2008) Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences*, **105**, 1786-1793.
- Lettenmaier, D.P., Wood, E.F. and Wallis, J.R. (1994) Hydro-Climatological Trends in the Continental United States, 1948-88. *Journal of Climate*, **7**, 586-607.
- Lorenz, E.N. (1975) Climate Predictability. In *The physical bases of climate and climate modelling.*, Vol. GARP Publication Series, Vol. 16. World Meteorological Organisation, Geneva, pp. 132-136.
- Lough, J.M. (2007) Tropical river flow and rainfall reconstructions from coral luminescence: Great Barrier Reef, Australia. *Paleoceanography*, **22**, n/a-n/a.
- Lucas, C., Hennessy, K., Mills, G. and Bathols, J. (2007) Bushfire weather in Southeast Australia: recent trends and projected climate change impacts, Bushfire Cooperative Research Centre, Bureau of Meteorology, CSIRO, Melbourne.
- Lucas, C. (2009) On developing a historical fire weather data-set for Australia. *Australian Meteorological and Oceanographic Journal* **60**, 1-14.
- Mahajan, V., Muller, E. and Srivastava, R.K. (1990) Determination of Adopter Categories by Using Innovation Diffusion Models. *Journal of Marketing Research*, **27**, 37-50.
- Mantua, N. and Hare, S. (2002) The Pacific Decadal Oscillation. *Journal of Oceanography*, **58**, 35-44.
- Markantonis, V., Meyer, V. and Schwarze, R. (2012) Valuating the intangible effects of natural hazards – review and analysis of the costing methods. *Natural Hazards and Earth System Sciences*, **12**, 1633-1640.
- Maronna, R. and Yohai, V.J. (1978) A bivariate test for the detection of a systematic change in mean. *Journal of the American Statistical Association*, **73**, 640-645.
- Masterman, M. (1970) The nature of a paradigm. In *Criticism and the growth of knowledge* (eds Lakatos, I. and Musgrave, A.). Cambridge University Press, Cambridge [Eng.], pp. 59-89.

- Mastrandrea, M.D., Field, C.B., Stocker, T.F., Edenhofer, O., Ebi, K.L., Frame, D.J., Held, H., Kriegler, E., Mach, K.J., Matschoss, P.R., Plattner, G.-K., Yohe, G.W. and Zwiers, F.W. (2010) Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Intergovernmental Panel on Climate Change. IPCC, Geneva.
- McBean, G. and Rodgers, C. (2010) Climate hazards and disasters: the need for capacity building. *Wiley Interdisciplinary Reviews: Climate Change*, **1**, 871-884.
- McCabe, G.J. and Wolock, D.M. (2002) A step increase in streamflow in the conterminous United States. *Geophysical Research Letters*, **29**, 38-31-38-34.
- McCook, L.J., Folke, C., Hughes, T., Nyström, M., Obura, D. and Salm, R. (2007) Ecological resilience, climate change and the Great Barrier Reef. *Climate change and the Great Barrier Reef. Townsville, Australia: Great Barrier Reef Marine Park Authority*.
- McMichael, A.J., Woodruff, R., Whetton, P., Hennessy, K., Nicholls, N., Hales, S., Woodward, A. and Kjellstrom, T. (2003) *Human Health and Climate Change in Oceania: A Risk Assessment 2002* Commonwealth of Australia, Canberra.
- Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J. and Zhao, Z.-C. (2007) Global Climate Projections. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Solomon, S. and D. Qin, M.M., Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 747-845.
- Meehl, G.A., Arblaster, J.M., Fasullo, J.T., Hu, A. and Trenberth, K.E. (2011) Model-based evidence of deep-ocean heat uptake during surface-temperature hiatus periods. *Nature Clim. Change*, **1**, 360-364.
- Menne, M. (2006) Abrupt global temperature change and the instrumental record. In *18th Conference on Climate Variability and Change*. American Meteorological Organisation, Atlanta, Georgia.
- Mercer, D., Christesen, L. and Buxton, M. (2007) Squandering the future—Climate change, policy failure and the water crisis in Australia. *Futures*, **39**, 272-287.
- Merz, B., Elmer, F. and Thielen, A.H. (2009) Significance of "high probability/low damage" versus "low probability/high damage" flood events. *Natural Hazards and Earth System Sciences*, **9**, 1033-1046.
- Millar, C.I., Stephenson, N.L. and Stephens, S.L. (2007) Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications*, **17**, 2145-2151.
- Miller, A.J., Cayan, D.R., Barnett, T.P., Graham, N.E. and Oberhuber, J.M. (1994) The 1976–77 climate shift of the Pacific Ocean. *Oceanography*, **7**, 21-26.
- Mills, K., Gell, P., Gergis, J., Baker, P., Finlayson, M., Hesse, P., Jones, R., Kershaw, P., Pearson, S., Treble, P., Barr, C., Brookhouse, M., Drysdale, R., McDonald, J., Haberle, S., Reid, M., Thoms, M. and Tibby, J. (In revision-a) Palaeoclimate studies and natural resource management in the Murray-Darling Basin II: unravelling past human impact and climate variability. *Australian Journal of Earth Sciences*.

- Mills, K., Gell, P., Hesse, P., Jones, R., Kershaw, P., Drysdale, R. and McDonald, J. (In revision-b) Palaeoclimate studies and natural resource management in the Murray-Darling Basin I: past, present and future climates. *Australian Journal of Earth Sciences*.
- Moench, M., Mechler, R. and Stapleton, S. (2007) Guidance note on the Costs and Benefits of Disaster Risk Reduction. In *ISDR, High level Platform on Disaster Risk Reduction June 4-7, 2007*, pp. 29.
- Morgan, M.G., Fischhoff, B., Bostrom, A. and Atman, C.J. (2001) *Risk Communication: A Mental Models Approach* Cambridge University Press, Cambridge.
- Murphy, J., Kattsov, V., Keenlyside, N., Kimoto, M., Meehl, J., Mehta, V., Pohlmann, H., Scaife, A. and Smith, D. (2009) Towards Prediction of Decadal Climate Variability and Change. In *World Climate Conference - 3: Better climate information for a better future*, Geneva, Switzerland.
- Naess, L.O., Bang, G., Eriksen, S. and Vevatne, J. (2005) Institutional adaptation to climate change: Flood responses at the municipal level in Norway. *Global Environmental Change-Human and Policy Dimensions*, **15**, 125-138.
- Nairn, J., Fawcett, R. and Ray, D. (2009) Defining and predicting excessive heat events, a national system. In *3rd CAWCR Modelling Workshop, 2009*. Centre for Australian Climate and Weather Research, Melbourne, pp. 4.
- Näslund, L. and Pemer, F. (2012) The appropriated language: Dominant stories as a source of organizational inertia. *Human Relations*, **65**, 89-110.
- National Emergency Management Committee (2010) *National Emergency Risk Assessment Guidelines* Tasmanian State Emergency Service, Hobart, Tasmania.
- Nelson, R., Kokic, P., Crimp, S., Meinke, H. and Howden, S.M. (2010) The vulnerability of Australian rural communities to climate variability and change: Part I--Conceptualising and measuring vulnerability. *Environmental Science & Policy*, **13**, 8-17.
- Neumayer, E. (2007) A missed opportunity: The Stern Review on climate change fails to tackle the issue of non-substitutable loss of natural capital. *Global Environmental Change*, **17**, 297-301.
- New South Wales Treasury (1997) Guidelines for Economic Appraisal. *Treasury Policy and Guidelines Paper 97-2*, New South Wales Treasury, Office of Financial Management,, Sydney, NSW.
- Nunes, P.A.L.D. and Ding, H. (2009) Climate change, ecosystem services and biodiversity loss: an economic assessment. *Policy Brief 08.2009*, Fondazione Eni Enrico Mattei (FEEM) Venice.
- O'Brien, K. (2012) Global environmental change II From adaptation to deliberate transformation. *Progress in Human Geography*, **36**, 667-676.
- Oberlack, C. and Neumärker, B. (2011) Economics, institutions and adaptation to climate change. *The Constitutional Economics Network Working Papers*, University of Freiburg, Department of Economic Policy and Constitutional Economic Theory, Freiberg, Germany.
- OECD (2006) *Cost-Benefit Analysis and the Environment: Recent Developments* OECD Publishing, Paris.

- Olsson, P., Folke, C. and Hughes, T.P. (2008) Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. *Proceedings of the National Academy of Sciences*, **105**, 9489-9494.
- Oreskes, N. and Conway, E.M. (2010) *Merchants of doubt : how a handful of scientists obscured the truth on issues from tobacco smoke to global warming*, 1st U.S. edn. Bloomsbury Press, New York.
- Osberghaus, D., Dannenberg, A., Mennel, T. and Sturm, B. (2010) The role of the government in adaptation to climate change. *Environment and Planning C: Government and Policy*, **28**, 834-850.
- Ostrom, E. (2005) *Understanding institutional diversity* Princeton University Press, Princeton.
- Ostrom, E. (2007a) Institutional Rational Choice: An Assessment of the Institutional Analysis and Development Framework. In *Theories of the Policy Process* (ed. Sabatier, P.A.). Westview Press, Boulder, CO, pp. 21-64.
- Ostrom, E. (2007b) A Diagnostic Approach for Going Beyond Panaceas. *Proceedings of the National Academy of Sciences*, **104**, 15181-15187.
- Ostrom, E., Janssen, M. and Anderies, J. (2007) Going Beyond Panaceas. *Proceedings of the National Academy of Sciences*, **104**, 15176–15178.
- Ostrom, E. (2011) Background on the Institutional Analysis and Development Framework. *Policy Studies Journal*, **39**, 7-27.
- Overland, J., Rodionov, S., Minobe, S. and Bond, N. (2008) North Pacific regime shifts: Definitions, issues and recent transitions. *Progress In Oceanography*, **77**, 92-102.
- Oxford Economics (2009) *Valuing the effects of Great Barrier Reef Bleaching* Great Barrier Reef Foundation, Newstead, Queensland.
- Parry, M.L. and Carter, T.R. (1998) *Climate impact and adaptation assessment : a guide to the IPCC approach* Earthscan, London.
- Patt, A.G. and Schrag, D.P. (2003) Using specific language to describe risk and probability. *Climatic Change*, **61**, 17-30.
- Pearce, D., Groom, B., Hepburn, C. and Koundouri, P. (2003) Valuing the future. *World Economics*, **4**, 121-141.
- Pelling, M. (2003) Social Capital and Institutional Adaptation to Climate Change. *RCC Working Paper 2*, Rapid Climate Change Project, <http://www.rcc.rures.net>.
- Perry, R.W. and Lindell, M.K. (1997) Principles for Managing Community Relocation as a Hazard Mitigation Measure. *Journal of Contingencies and Crisis Management*, **5**, 49-59.
- Pidgeon, N., Kasperson, R. and Slovic, P., eds. (2003) *The Social Amplification of Risk*. Cambridge University Press, Cambridge, pp 468.
- Pielke Jr, R.A. and Sarewitz, D. (2005) Bringing Society Back into the Climate Debate. *Population & Environment*, **26**, 255-268.
- Pierrehumbert, R.T. (2011) Infrared radiation and planetary temperature. *Physics Today*, **64**, 33-38.

- Pittock, A.B. and Jones, R.N. (2000) Adaptation to what and why? *Environmental Monitoring and Assessment*, **61**, 9-35.
- Potter, K. (1981) Illustration of a new test for detecting a shift in mean in precipitation series. *Monthly Weather Review*, **109**, 2040-2045.
- Power, S., Tseitkin, F., Mehta, V., Lavery, B., Torok, S. and Holbrook, N. (1999) Decadal climate variability in Australia during the twentieth century. *International Journal of Climatology*, **19**, 169-184.
- Power, S., Sadler, B. and Nicholls, N. (2005) The influence of climate science on water management in Western Australia - Lessons for climate scientists. *Bulletin of the American Meteorological Society*, **86**, 839-+.
- Power, S., Haylock, M., Colman, R. and Wang, X. (2006) The Predictability of Interdecadal Changes in ENSO Activity and ENSO Teleconnections. *Journal of Climate*, **19**, 4755-4771.
- Preston, B.L., Jones, R.N., CSIRO Marine and Atmospheric Research. and Australian Business Roundtable on Climate Change. (2006) Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions a consultancy report for the Australian Business Roundtable on Climate Change. CSIRO, [Aspendale, Vic].
- Preston, B.L., Jones, R.N. and Hennessy, K.J. (2007) Application of climate projections in impact and risk assessments. In *Climate Change in Australia: Technical Report 2007* (ed. BoM, C.a.). CSIRO and BoM, Melbourne, pp. 108-123.
- Preston, B.L. and Stafford-Smith, M. (2009) Framing vulnerability and adaptive capacity assessment: Discussion paper. *CSIRO Climate Adaptation Flagship Working Paper No. 2*, CSIRO, Canberra.
- Productivity Commission (2012) Barriers to Effective Climate Change Adaptation. *Productivity Commission Issues Paper*, Productivity Commission, Canberra.
- Queensland Treasury (2006) Cost-Benefit Analysis Guidelines Achieving Value for Money In Public Infrastructure and Service Delivery. *Project Assurance Framework Supplementary Guidance Material, Version 0.3*, Queensland Treasury, Brisbane.
- Queensland University of Technology (2010) Impacts and adaptation responses of infrastructure and communities to heatwaves: the southern Australian experience of 2009, National Climate Change Adaptation Research Facility, Gold Coast, Australia.
- Quiggin, J. and Horowitz, J. (2003) Costs of adjustment to climate change. *The Australian Journal of Agricultural and Resource Economics*, **47**, 429-446.
- Quiggin, J., Adamson, D., Chambers, S. and Schrobback, P. (2010) Climate Change, Uncertainty, and Adaptation: The Case of Irrigated Agriculture in the Murray–Darling Basin in Australia. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, **58**, 531-554.
- Ranger, N., Millner, A., Dietz, S., Fankhauser, S., Lopez, A. and Ruta, G. (2010) Adaptation in the UK: a decision making process. *Grantham/CCCEP Policy Brief*, Environment Agency, London, UK.

- Ranger, N. and Garbett-Shiels, S.-L. (2012) Accounting for a changing and uncertain climate in planning and policymaking today: lessons for developing countries. *Climate and Development*, **4**, 288-300.
- Raper, S.C.B., Gregory, J.M. and Osborn, T.J. (2001) Use of an upwelling-diffusion energy balance climate model to simulate and diagnose A/OGCM results. *Climate Dynamics*, **17**, 601-613.
- Raper, S.C.B., Gregory, J.M. and Stouffer, R.J. (2002) The role of climate sensitivity and ocean heat uptake on AOGCM transient temperature response. *Journal of Climate*, **15**, 124-130.
- Rayner, S. and Malone, E.L. (1998) *Human choice and climate change* Battelle Press, Columbus, Ohio.
- Renn, O. (2011) The social amplification/attenuation of risk framework: application to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, **2**, 154-169.
- Reser, J.P., Morrissey, S.A. and Ellul, M. (2011) The threat of climate change: Psychological response, adaptation, and impacts. In *Climate change and human well-being: Global challenges and opportunities* (ed. Weissbecker, I.). Springer Science, New York, NY, pp. 19-42.
- Rial, J.A., Pielke, R.A., Sr., Beniston, M., Claussen, M., Canadell, J., Cox, P., Held, H., de Noblet-Ducoudré, N., Prinn, R., Reynolds, J.F. and Salas, J.D. (2004) Nonlinearities, Feedbacks and Critical Thresholds within the Earth's Climate System. *Climatic Change*, **65**, 11-38.
- Rickards, L. and Howden, S. (2012) Transformational adaptation: agriculture and climate change. *Crop and Pasture Science*, **63**, 240-250.
- Risbey, J.S. (2008) The new climate discourse: alarmist or alarming? *Global Environmental Change*, **18**, 26-37.
- Roberts, A.M., Seymour, E.J. and Pannell, D.J. (2011) The Role of Regional Organisations in Managing Environmental Water in the Murray–Darling Basin, Australia*. *Economic Papers: A journal of applied economics and policy*, **30**, 147-156.
- Rodionov, S.N. (2005) A brief overview of the regime shift detection methods. In *Large-Scale Disturbances (Regime Shifts) and Recovery in Aquatic Ecosystems: Challenges for Management Toward Sustainability. UNESCO-ROSTE/BAS Workshop on Regime Shifts* (eds. Velikova, V. and Chipev, N.), Varna, Bulgaria, pp. 17-24.
- Rodionov, S.N. (2006) Use of prewhitening in climate regime shift detection. *Geophysical Research Letters*, **33**, L12707.
- Roe, G. (2009) Feedbacks, Timescales, and Seeing Red. *Annual Review of Earth and Planetary Sciences*, **37**, 93-115.
- Rogers, E.M. and Kincaid, D.L. (1981) *Communication networks : toward a new paradigm for research* Free Press, New York.
- Rogers, E.M. (2003) *Diffusion of innovations*, 5th edn. Free Press, New York.
- Röling, N. and Maarleveld, M. (1999) Facing strategic narratives: In which we argue interactive effectiveness. *Agriculture and Human Values*, **16**, 295-308.

- Rosa, E. (2003) The logical structure of the social amplification of risk framework (SARF): metatheoretical foundations and policy implications. In *The Social Amplification of Risk* (eds Pidgeon, N., Kasperson, R. and Slovic, P.). Cambridge University Press, Cambridge, pp. 46-76.
- Ruggieri, E. (2013) A Bayesian approach to detecting change points in climatic records. *International Journal of Climatology*, **33**, 520-528.
- Santer, B.D., Wigley, T.M.L., Schlesinger, M.E. and Mitchell, J.F.B. (1990) Developing climate scenarios from equilibrium GCM results. *Research Report No. 47*, Max Planck Institut für Meteorologie, Hamburg.
- Santer, B.D., Mears, C., Doutriaux, C., Caldwell, P., Gleckler, P.J., Wigley, T.M.L., Solomon, S., Gillett, N.P., Ivanova, D., Karl, T.R., Lanzante, J.R., Meehl, G.A., Stott, P.A., Taylor, K.E., Thorne, P.W., Wehner, M.F. and Wentz, F.J. (2011) Separating signal and noise in atmospheric temperature changes: The importance of timescale. *J. Geophys. Res.*, **116**, D22105.
- Sarewitz, D. and Pielke Jr, R.A. (2007) The neglected heart of science policy: reconciling supply of and demand for science. *Environmental Science & Policy*, **10**, 5-16.
- Schneider, N., Miller, A.J. and Pierce, D.W. (2002) Anatomy of North Pacific decadal variability. *Journal of Climate*, **15**, 586-605.
- Schneider, S.H. (2004) Abrupt non-linear climate change, irreversibility and surprise. *Global Environmental Change*, **14**, 245-258.
- Schneider, S.H. and Lane, J. (2006) An overview of 'dangerous' climate change. In *Avoiding Dangerous Climate Change* (eds Schellnhuber, H.J., Cramer, W., Nakicenovic, N., Wigley, T. and Yohe, G.). Cambridge University Press, Cambridge, UK, pp. 7-23.
- Schwartz, P. and Randall, D. (2003) An abrupt climate change scenario and its implications for United States national security, Defence Technical Information Centre, Fort Belvoir, VA.
- Schwing, F.B., Jiang, J. and Mendelssohn, R. (2003) Coherency of multi-scale abrupt changes between the NAO, NPI, and PDO. *Geophysical Research Letters*, **30**, n/a-n/a.
- Seidel, D.J. and Lanzante, J.R. (2004) An assessment of three alternatives to linear trends for characterizing global atmospheric temperature changes. *J. Geophys. Res.*, **109**, D14108.
- Shackley, S., Young, P., Parkinson, S. and Wynne, B. (1998) Uncertainty, complexity and concepts of good science in climate change modelling: Are GCMs the best tools? *Climatic Change*, **38**, 159-205.
- Shaw, R., Pulhin, J.M. and Pereira, J.J. (2010) Climate change adaptation and disaster risk reduction: overview of issues and challenges. In *Climate Change Adaptation and Disaster Risk Reduction: Issues and Challenges* (ed. Rajib Shaw, J.M.P., Joy Jacqueline Pereira). Emerald Group, Bingley, UK, pp. 1-19.
- Shaxson, L., Bielak, A., Ahmed, I., Brien, D., Conant, B., Fisher, C., Gwyn, E. and Klerkx, L. (2012) *Expanding our understanding of K*(Kt, KE, Ktt, KMb, KB, KM, etc.): a concept paper emerging from the K* conference held in Hamilton, Ontario, Canada, April 2012* United Nations University – Institute for Water, Environment and Health,, Hamilton, Ontario, Canada.

- Sheate, W.R. and Partidário, M.R. (2010) Strategic approaches and assessment techniques— Potential for knowledge brokerage towards sustainability. *Environmental Impact Assessment Review*, **30**, 278-288.
- Sherwood, S. (2011) Science controversies past and present. *Physics Today*, **64**, 39-44.
- Shwom, R., Dan, A. and Dietz, T. (2008) The effects of information and state of residence on climate change policy preferences. *Climatic Change*, **90**, 343-358.
- Siebenhüner, B. (2002) How do scientific assessments learn?: Part 1. Conceptual framework and case study of the IPCC. *Environmental Science & Policy*, **5**, 411-420.
- Smit, B., Burton, I., Klein, R.T. and Wandel, J. (2000) An Anatomy of Adaptation to Climate Change and Variability. In *Societal Adaptation to Climate Variability and Change* (eds Kane, S. and Yohe, G.). Springer Netherlands, pp. 223-251.
- Smith, J.B., H.-J. S., Mirza, M.M.Q., Fankhauser, S., Leemans, R., Erda, L., Ogallo, L., Pittock, B., Richels, R., Rosenzweig, C., Safriel, U., Tol, R.S.J., Weyant, J. and Yohe, G. (2001) Vulnerability to Climate Change and Reasons for Concern: A Synthesis. In *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (eds McCarthy, J.J., Canziani, O.F., Leary, N.A., Docken, D.J. and White, K.S.). Cambridge University Press, Cambridge and New York, pp. 913-967.
- Smithers, J. and Smit, B. (1997) Human adaptation to climatic variability and change. *Global Environmental Change*, **7**, 129-146.
- Solomon, A., Goddard, L., Kumar, A., Carton, J., Deser, C., Fukumori, I., Greene, A.M., Hegerl, G., Kirtman, B., Kushnir, Y., Newman, M., Smith, D., Vimont, D., Delworth, T., Meehl, G.A. and Stockdale, T. (2010) Distinguishing the Roles of Natural and Anthropogenically Forced Decadal Climate Variability. *Bulletin of the American Meteorological Society*, **92**, 141-156.
- Standards Australia and Standards New Zealand (2004) AS/NZS Australian/New Zealand Standard for Risk Management: AS/NZS 4360 2004. Standards Australia and Standards New Zealand, pp. 38.
- Statistics Sweden (2012) Climate Change Adaptation Expenditure – A proposal for a methodology to compile, define and classify national and EU economic information as statistics, Statistics Sweden, Stockholm Sweden.
- Stavins, R.N. (2000) Market-Based Environmental Policies. In *Public Policies for Environmental Protection* (eds Portney, P.R. and Stavins, R.N.). Resources for the Future, Washington, DC.
- Stavins, R.N. (2001) Lessons From the American Experiment With Market-Based Environmental Policies *Discussion Paper 01–53*, Resources for the Future, Washington DC.
- Stephenson, C. (2010) The impacts, losses and benefits sustained from five severe bushfire in south-eastern Australia. *Research Report 88*, Bushfire Cooperative Research Centre, Melbourne.
- Stern, N.H. and Treasury of Great Britain (2007) *The economics of climate change: the Stern review* Cambridge University Press, Cambridge, UK ; New York.

- Stigler, S.M. (1986) *The History of Statistics: The Measurement of Uncertainty Before 1900* Belknap Press of Harvard University Press, Cambridge, MA.
- Stiglitz, J.E., Sen, A. and Fitoussi, J.P. (2009) Report by the commission on the measurement of economic performance and social progress, Commission on the Measurement of Economic Performance and Social Progress.
- Suppiah, R., Hennessy, K.J., Whetton, P.H., McInnes, K.L., Macadam, I., Bathols, J.M., Ricketts, J.H. and Page, C.M. (2007) Australian climate change projections derived from simulations performed for the IPCC 4th Assessment Report. *Australian Meteorological Magazine*, **56**.
- Swanson, K.L., Sugihara, G. and Tsonis, A.A. (2009) Long-term natural variability and 20th century climate change. *Proceedings of the National Academy of Sciences*, **106**, 16120-16123.
- Swanson, K.L. and Tsonis, A.A. (2009) Has the climate recently shifted? *Geophys. Res. Lett.*, **36**, L06711.
- Swart, R., Bernstein, L., Ha-Duong, M. and Petersen, A. (2009) Agreeing to disagree: uncertainty management in assessing climate change, impacts and responses by the IPCC. *Climatic Change*, **92**, 1-29.
- Swetnam, T.W. and Betancourt, J.L. (2010) Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. In *Tree Rings and Natural Hazards: A State-Of-The-Art* (ed. Stoffel, M.). Springer, Dordrecht, pp. 329-359.
- Taylor, K.E., Stouffer, R.J. and Meehl, G.A. (2012) An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, **93**, 485-498.
- Teague, B., McLeod, R. and Pascoe, S. (2010) Final Report: Summary, 2009 Victorian Bushfires Royal Commission, Melbourne.
- Tebaldi, C., Smith, R.L., Nychka, D. and Mearns, L.O. (2005) Quantifying Uncertainty in Projections of Regional Climate Change: A Bayesian Approach to the Analysis of Multimodel Ensembles. *Journal of Climate*, **18**, 1524-1540.
- Tebaldi, C. and Knutti, R. (2007) The use of the multi-model ensemble in probabilistic climate projections. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **365**, 2053-2075.
- TEEB (2009) The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations, The Economics of Ecosystems and Biodiversity.
- Tomé, A.R. and Miranda, P.M.A. (2004) Piecewise linear fitting and trend changing points of climate parameters. *Geophysical Research Letters*, **31**, L019100.
- Travis, W. (2010) Going to extremes: propositions on the social response to severe climate change. *Climatic Change*, **98**, 1-19.
- Trenberth, K. (2002) Earth System Processes. In *Encyclopedia of Global Environmental Change. Volume 1, The Earth system: physical and chemical dimensions of global environmental change* (eds MacCracken, M.C. and Perry, J.S.). John Wiley & Sons, Ltd, Chichester, UK, pp. 13-30.

- Trenberth, K.E., Fasullo, J.T. and Kiehl, J. (2009) Earth's global energy budget. *Bulletin of the American Meteorological Society*, **90**, 311-323.
- Trenberth, K.E. and Fasullo, J.T. (2010) Tracking Earth's Energy. *Science*, **328**, 316-317.
- Tribbia, J. and Moser, S.C. (2008) More than information: what coastal managers need to plan for climate change. *Environmental Science & Policy*, **11**, 315-328.
- Tsonis, A.A., Swanson, K. and Kravtsov, S. (2007) A new dynamical mechanism for major climate shifts. *Geophysical Research Letters*, **34**, GL030288.
- Turner, G., Baynes, T. and West, J. (2007) Combined pressures and climate change impacts on the Victorian water system and possible responses. In MODSIM 2007 - Land, Water and Environmental Management: Integrated Systems for Sustainability (ed. by Oxley, L. and Kulasiri, D.). Modelling and Simulation Society of Australia and New Zealand, New Zealand, pp. 567-573.
- Turner, G.M., Hoffman, R., McInnis, B.C., Poldy, F. and Foran, B. (2011) A tool for strategic biophysical assessment of a national economy—The Australian Stocks and Flows Framework. *Environmental Modelling & Software*, **26**, 1134-1149.
- Tversky, A. and Kahneman, D. (1992) Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, **5**, 297-323.
- Tversky, A. and Kahneman, D. (2000) Judgement under uncertainty: heuristics and biases. In *Judgment and decision making: an interdisciplinary reader* (eds Connolly, T., Arkes, H.R. and Hammond, K.R.). Cambridge University Press, Cambridge, pp. 35-52.
- UNDP (2005) *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures* Cambridge University Press, Cambridge and New York.
- UNFCCC (2009) Potential costs and benefits of adaptation options: A review of existing literature. *Technical Paper 2009/2*, Framework Convention on Climate Change, United Nations, Geneva.
- Urban Capacity Building Network (n.d.) Defining Capacity Building. Global Development Research Center, Kobe, Japan.
- Van de Ven, A.H. and Rogers, E.M. (1988) Innovations and Organisations—Critical Perspectives. *Communication Research*, **15**, 632–651.
- Van der Sluijs, J., Risbey, J., Klopogge, P., Ravetz, J., Funtowicz, S., Corral Quintana, S., Guimaraes Pereira, A., De Marchi, B., Petersen, A. and Janssen, P. (2003) RIVM/MNP guidance for uncertainty assessment and communication: Detailed guidance. *Copernicus Institute for Sustainable Development, Universit t Utrecht und RIVM-MNP, Utrecht*.
- Venkatachalam, L. (2004) The contingent valuation method: a review. *Environmental Impact Assessment Review*, **24**, 89–124.
- Verdon, D.C., Wyatt, A.M., Kiem, A.S. and Franks, S.W. (2004) Multidecadal variability of rainfall and streamflow: Eastern Australia. *Water Resour. Res.*, **40**, W10201.
- Verdon, D.C. and Franks, S.W. (2006) Long-term behaviour of ENSO: Interactions with the PDO over the past 400 years inferred from paleoclimate records. *Geophys. Res. Lett.*, **33**, L06712.

- Victorian Competition and Efficiency Commission (2007) Guidance Note on Discounting. Victorian Competition and Efficiency Commission, Melbourne.
- Victorian Department of Treasury and Finance (2007) *Victorian Guide to Regulation*, 2nd edn. Victorian Department of Treasury and Finance, Melbourne.
- Viehöver, W. (2011) Governing the Planetary Greenhouse in Spite of Scientific Uncertainty. *Science, Technology and Innovation Studies*, **6**, 127-154.
- Visser, K., Thunell, R. and Stott, L. (2003) Magnitude and timing of temperature change in the Indo-Pacific warm pool during deglaciation. *Nature*, **421**, 152-155.
- Vivès, B. and Jones, R.N. (2005) Detection of Abrupt Changes in Australian Decadal Rainfall (1890-1989). *CSIRO Atmospheric Research Technical Paper*, CSIRO Atmospheric Research, Melbourne.
- Wang, G., Swanson, K.L. and Tsonis, A.A. (2009) The pacemaker of major climate shifts. *Geophysical Research Letters*, **36**, n/a-n/a.
- Warner, R.F. (1995) Predicting and managing channel change in Southeast Australia. *Catena*, **25**, 403-418.
- Washington, D. (2013) Heatwaves a risk to the mentally ill. In Adelaide InDaily. Solstice Media, Adelaide.
- Watterson, I.G. (2008) Calculation of probability density functions for temperature and precipitation change under global warming. *Journal of Geophysical Research: Atmospheres*, **113**, n/a-n/a.
- Weart, S.R. (2008) *The Discovery of Global Warming* Harvard University Press, Cambridge, MA.
- Webb, R. and Beh, J.-I. (2013) *Leading adaptation practices and support strategies for Australia: An international and Australian review of products and tools* National Climate Change Adaptation Research Facility, Gold Coast.
- Weitzman, M. (2007a) Structural Uncertainty and the Value of Statistical Life in the Economics of Catastrophic Climate Change. *National Bureau of Economic Research Working Paper Series*, **No. 13490**.
- Weitzman, M.L. (2007b) A Review of The Stern Review on the Economics of Climate Change. *Journal of Economic Literature*, **45**, 703-724.
- Welp, M., Anne, C., Stoll-Kleemann, S. and Fürstenau, C. (2006) Science-based stakeholder dialogues in climate change research. In *Stakeholder Dialogues in Natural Resources Management*. Springer, pp. 213-240.
- Whetton, P. (2011) Future Australian climate scenarios. In *Climate Change: Science and Solutions for Australia* (eds Cleugh, H., Smith, M.S., Battaglia, M. and Graham, P.). CSIRO, Melbourne, pp. 35-44.
- Whetton, P.H., Jones, R.N., McInnes, K.L., Hennessy, K.J., Suppiah, R., Page, C.M., Bathols, J., Durack, P.J. and CSIRO Marine and Atmospheric Research. (2005) Australian climate change projections for impact assessment and policy application : a review. In CSIRO Marine and Atmospheric Research paper,. CSIRO Marine and Atmospheric Research, Aspendale, Vic.

- Whitten, S., Bueren, M. and Collins, D. (2004) Setting the scene: What are market-based tools and why use them? An overview of market-based instruments and environmental policy in Australia. In *6th Annual AARES National Symposium 2003*. RIRDC Publication No 04/142, Canberra, pp. 6-14.
- Wigley, T.M.L., Smith, R.L. and Santer, B.D. (1999) The autocorrelation function and human influences on climate. *Science*, **285**, 495a.
- Wilby, R.L. and Dessai, S. (2010) Robust adaptation to climate change. *Weather*, **65**, 180-185.
- Willows, R. and Connell, R. (2003) *Climate Adaptation: Risk, Uncertainty, and Decision-making* UK Climate Impacts Programme, Oxford.
- Wilmking, M., D'Arrigo, R., Jacoby, G. and Juday, G. (2005) Increased temperature sensitivity and divergent growth trends in circumpolar boreal forests. *Geophysical Research Letters*, **32**, L15715.
- Wise, M.N. (1993) Mediations: Enlightenment balancing acts, or the technologies of rationalism. In *World changes: Thomas Kuhn and the nature of science* (ed. Horwich, P.). MIT Press, Cambridge, MA.
- World Bank (2010) The economics of adaptation to climate change, A Synthesis Report, Final Consultation Draft. World Bank, Washington DC.
- World Meteorological Organization (2010) *Position Paper on Global Framework for Climate Services* World Meteorological Organisation, Geneva.
- World Meteorological Organization (2011) Climate Knowledge for Action: A Global Framework for Climate Services - Empowering the Most Vulnerable. *Report No. 1065* World Meteorological Organization, Geneva.
- WUCA (2010) *Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning* Water Utility Climate Alliance, San Francisco, CA.
- Wynne, B. (2010) When doubt becomes a weapon. *Nature*, **466**, 441-442.
- Yohe, G. and Tol, R.S.J. (2002) Indicators for social and economic coping capacity - moving toward a working definition of adaptive capacity. *Global Environmental Change*, **12**, 25-40
- Yohe, G.W., Lasco, R.D., Ahmad, Q.K., Arnell, N.W., Cohen, S.J., Hope, C., Janetos, A.C. and Perez, R.T. (2007) Perspectives on climate change and sustainability. . In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Parry, M.L., Canziani, O.F., Palutikof, J.P., Linden, P.J.v.d. and Hanson, C.E.). Cambridge University Press, Cambridge, UK, pp. 811-841.
- Yohe, G.W. and Tol, R.S. (2008) The Stern Review and the economics of climate change: an editorial essay. *Climatic Change*, **89**, 231-240.
- Young, C. (2012) Communicating Adaptation Effectively. In *Adaptation in Action 2012: National Climate Change Adaptation Conference*. National Climate Change Adaptation Research Facility, 26-28 June 2012 Sebel Hotel Albert Park, Melbourne.

- Young, C. (2013) Communicating for Change. In *XIX International Conference of the Society for Human Ecology, jointly with IV International Conference on Sustainability Science in Asia*. Society for Human Ecology, Canberra, Australia, 7 February 2013.
- Young, C.K. and Jones, R.N. (2012) Industry Roundtable Context Paper, Victorian Centre for Climate Change Adaptation Research, Melbourne.
- Young, O.R., King, L.A. and Schroeder, H. (2008) *Institutions and environmental change: principal findings, applications, and research frontiers* MIT Press, Cambridge, Mass.
- Zaltman, G., Duncan, R. and Holbek, J. (1973) *Innovations and organizations* Wiley, New York,.
- Zhang, D. and McPhaden, M.J. (2006) Decadal variability of the shallow Pacific meridional overturning circulation: Relation to tropical sea surface temperatures in observations and climate change models. *Ocean Modelling*, **15**, 250-273.

