CoastAdapt

Assessing costs and benefits of adaptation

Information Manual 4

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Assessing the costs and benefits of coastal climate adaptation

Information Manual 4

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Preface

In 2014, the National Climate Change Adaptation Research Facility (NCCARF) was commissioned by the Australian Government to produce a coastal climate risk management tool in support of coastal managers adapting to climate change and sea-level rise. This online tool, known as CoastAdapt, provides information on all aspects of coastal adaptation as well as a decision support framework. It can be accessed at www.coastadapt.com.au.

Coastal adaptation encompasses many disciplines ranging from engineering through to economics and the law. Necessarily, therefore, CoastAdapt provides information and guidance at a level that is readily accessible to non-specialists. In order to provide further detail and greater insights, the decision was made to produce a set of Information Manuals, which would provide the scientific and technical underpinning and authoritativeness of CoastAdapt. The topics for these Manuals were identified in consultation with potential users of CoastAdapt.

There are ten Information Manuals, covering all aspects of coastal adaptation, as follows:

1. Building the knowledge base for adaptation action
2. Understanding sea-level rise and climate change, and associated impacts on the coastal zone
3. Available data, datasets and derived information to support coastal hazard assessment and adaptation planning
4. Assessing the costs and benefits of coastal climate adaptation
5. Adapting to long term coastal climate risks through planning approaches and instruments
6. Legal risk. A guide to legal decision making in the face of climate change for coastal decision makers
7. Engineering solutions for coastal infrastructure
8. Coastal sediments, beaches and other soft shores
9. Community engagement
10. Climate change adaptation planning for protection of coastal ecosystems

The Information Manuals have been written and reviewed by experts in their field from around Australia and overseas. They are extensively referenced from within CoastAdapt to provide users with further information and evidence.

NCCARF would like to express its gratitude to all who contributed to the production of these Information Manuals for their support in ensuring that CoastAdapt has a foundation in robust, comprehensive and up-to-date information.

1 Explanation of the structure of this manual and how to use it

This report refers to the full array of approaches that are available to decision-makers to assess the costs and benefits of adaptation interventions. These approaches include the traditional approaches such as cost-benefit analysis, cost-effectiveness analysis, and multi-criteria analyses along with the more robust approaches to decision-making that are more useful and relevant in contexts of 'deep' or 'fundamental' uncertainty[1] including portfolio analysis, real-options analysis, and robust decision-making (Dittrich et al., 2016).

There are many guidelines, textbooks and articles that explain and critique approaches to assessing costs and benefits. The purpose of this information manual is not to replicate these guidelines and instructions. A list of links to guidelines, critiques and case studies of traditional and robust approaches to assessing costs and benefits are provided in Table 1.

The purpose of this manual is to provide readers with information and advice on how to navigate the difficult landscape of deciding when, why and how to assess the costs and benefits of adaptation. We recommend reading this manual to complement other resources that provide guidance on how to use methods for comparing costs and benefits; particularly if you are not familiar with these approaches. This information manual therefore will help you decide which assessment method will be most useful to you, according to your needs. Ultimately, the purpose of this manual is to help you become an informed purchaser or user of economic assessments of adaptation options.

Each section of this manual explores specific issues that are critical to making defensible, efficient, and legitimate decisions and often reported by decision-makers to be least understood or practiced and most challenging, particularly in the context of uncertainty. The sections are also presented in a sequence and structure that starts with challenges in simpler contexts where the traditional narrow approach to cost benefit analysis (CBA) can be readily and meaningfully applied. It then moves to the more complex contexts characterized with high uncertainty, contested values and multiple decision-makers where more complicated, adaptive, and novel approaches to decision-making and cost-benefit assessment need to be developed and applied. The specific issues covered are:

- when and how to incorporate assessments of costs and benefits into decision-making
- reflecting on the general stages of decision-making (Fig 2a) to explicitly consider the nature of the assessments of costs and benefits that need to be done at each of these stages
- how to decide whether you need more information or not in order to make decisions
- examples are provided of assessments of the costs and benefits of avoiding coastal climate-change damage

[1] Fundamental uncertainty describes situations where not only the probability of an event happening is not known but the possible outcomes are also not known or are unknowable (Lempert et al. 2003; Perrings 2007).

Table 1: Examples of guidelines for the design and use of cost-benefit assessments, particularly those focused on assessing climate change adaptation

Guides to conventional cost-benefit analysis approaches

Buncle, A., A. Daigneault, P. Holland, A. Fink, S. Hook, and M. Manley, 2013: Cost-Benefit Analysis for natural resource management in the Pacific: A guide. Accessed 9 May 2016. [Available online at http://www.cepf.net/SiteCollectionDocuments/poly_micro/CostBenefitAnalysisNaturalResourceManagementPacific.pdf].

Mishan, E., and E. Quah, 2007: Cost-benefit analysis. 5th ed. Routledge, NY.

NSW Government, 2015: NSW Coastal Management Manual. Part C: Coastal Management Toolkit. Using Cost–Benefit Analysis to assess coastal management options: Guidance for councils. Consultation Draft. Office of Environment and Heritage. Accessed 9 May 2016. [Available online at http://www.environment.nsw.gov.au/resources/coasts/150805-cost-benefit-analysis.pdf].

NSW Government, 2007: NSW Government Guidelines for Economic Appraisal. Policy and Guidelines Paper. Office of Financial Management, NSW Treasury. Accessed 9 May 2016. [Available online at http://www.treasury.nsw.gov.au/__data/assets/pdf_file/0016/7414/tpp07-5.pdf].

Pannell, D., 2016: Sensitivity analysis: strategies, methods, concepts, examples. Accessed 20 April 2016. [Available online at http://dpannell.fnas.uwa.edu.au/dpap971f.htm].

QLD Government, 2015: Project Assessment Framework: Cost-benefit analysis. Component of the Project Assessment Framework. QLD Treasury. Accessed 9 May 2016. [Available online at https://www.treasury.qld.gov.au/publications-resources/project-assessment-framework/paf-cost-benefit-analysis.pdf].

Schuck, P.H., 2014: Why government fails so often: and how it can do better. Princeton University Press.

Guides to assessing the costs and benefits of climate adaptation

AECOM Australia, 2010: Coastal inundation at Narrabeen Lagoon: Optimising adaptation investment. Report for the Department of Climate Change and Energy and Efficiency. Accessed 9 May 2016. [Available online at http://www.environment.gov.au/climate-change/adaptation/publications/coastal-inundation-narrabeen-lagoon-optimising-adaptation-investment].

AECOM Australia, 2010: Securing long-term water supply in a time of climatic uncertainty: Prioritising adaptation investment. Report for the Department of Climate Change and Energy and Efficiency. Accessed 9 May 2016. [Available online at http://www.environment.gov.au/climate-change/adaptation/publications/securing-water-supply].

AECOM Australia, 2011: Adaptation of Melbourne's metropolitan rail network in response to climate change. Report for the Department of Climate Change and Energy and Efficiency. Accessed 9 May 2016. [Available online at http://www.environment.gov.au/climate-change/adaptation/publications/adaptation-melbournes-metropolitan-rail-network-response-climate-change].

AECOM Australia, 2012: Economic framework for analysis of climate change adaptation options. Report for the Commonwealth Department of Environment. Accessed 9 May 2016. [Available online at http://www.environment.gov.au/climate-change/adaptation/publications/economic-framework-analysis-adaptation-options].

Queensland University of Technology, 2010: Impacts and adaptation response of infrastructure and communities to heatwaves: the southern Australian experience of 2009. Report for the National Climate Change Adaptation Research Facility, Gold Coast, Australia. Accessed 9 May 2016. [Available online at https://www.nccarf.edu.au/publications/impacts-and-adaptation-responses-infrastructure-and-communities-heatwaves].

Rissik, D. and N. Reis, 2013: Tasmanian Climate Change Adaptation Pathways Project. Accessed 9 May 2016. [Available online at https://www.nccarf.edu.au/localgov/case-study/tasmanian-climate-change-adaptation-pathways-project].

Rissik, D. and N. Reis, 2013: Decision Support for Coastal Adaptation Action: The Handbook - Hunter region. Accessed 9 May 2016. [Available online at https://www.nccarf.edu.au/localgov/case-study/decision-support-coastal-adaptation-action-handbook-hunter-region].

Table 1: Examples of guidelines for the design and use of cost-benefit assessments, particularly those focused on assessing climate change adaptation - *continued*.

Guides to using decision-making frameworks

Dittrich, R., A. Wreford, and D. Moran, 2016: A survey of decision-making approaches for climate change adaptation: Are robust methods the way forward? *Ecological Economics*, **122**, 79-89.

Hertzler, G., 2007: Adapting to climate change and managing climate risks by using real options. *Australian Journal of Agricultural Research*, **58**, 985–992.

Kingsford, R. and H. Biggs, 2012: Strategic adaptive management guidelines for effective conservation of freshwater ecosystems in and around protected areas of the world. IUCN WCPA Freshwater Taskforce, Australian Wetlands and Rivers Centre, Sydney.

National Emergency Management Committee, 2010: National Emergency Risk Assessment Guidelines. Tasmanian State Emergency Service, Hobart. Accessed 9 May 2016. [Available online at http://coastaladaptationresources.org/PDF-files/1438-National-Emergency-Risk-Assessment-Guidelines-Oct-2010.PDF].

Pannell, D., and Coauthors, 2016: Investment Framework for Environmental Resources (INFFER). Accessed 9 May 2016. [Available online at http://www.inffer.com.au/].

Randall, A., T. Capon, T. Sanderson, D. Merrett, and G. Hertzler, 2012: Choosing a decision-making framework to manage uncertainty in climate adaptation decision-making: a practitioner's handbook. Report for the National Climate Change Adaptation Research Facility (NCCARF), Griffith University. Accessed 20 April 2016. [Available online at https://www.nccarf.edu.au/publications/Handbook-decision-making-framework-climate-adaptation].

Sanderson, T., G. Hertzler, T. Capon, and P. Hayman, 2016: A real-options analysis of Australian wheat production under climate change. *Australian Journal of Agricultural and Resource Economics*, **60**, 79-96. doi: 10.1111/1467-8489.12104.

Walker, B. and D. Salt, 2006: *Resilience Thinking: Sustaining Ecosystems and People in a Changing World.* Island Press, Washington, DC.

Guides to assessing values

Capon T., M. Parsons, and M. Thoms, 2009: Floodplain Ecosystems: resilience, value of ecosystem services, and principles for diverting water from floodplains. Waterlines Report Series No. 22. Accessed 9 May 2016.

Kenter, J.O., and Coauthors, 2015: What are shared and social values of ecosystems? *Ecological Economics*, **111**, 86-99.

Mezey, E. and J. Conrad, 2010: Real options in Resource Economics. *Annual Review of Resource Economics*, **2**(1), 33-52.

Russell, C., 2001: Applying economics to the environment. Oxford University Press, 400 pp.

Stern, N. 2012: Ethics, equity and the economics of climate change. Centre for Climate Change Economics and Policy, Working Paper No. 97. Grantham Research Institute on Climate Change and the Environment, Working Paper No. 84. Accessed 20 April 2016. [Available online at http://re.indiaenvironmentportal.org.in/files/file/ethics-equity-economics-of-climate-change.pdf].

2 When and how should costs and benefits be assessed?

The book, "Wolves, Bears, and Their Prey in Alaska," (NRC 1997) outlines the general structure of all decisions. Decisions consist of two main elements, (1) the choice set – the alternatives to be considered, and (2) the objective function – the criteria used to choose among alternatives. The costs and benefits associated with the alternatives are identified and defined by the objective function, and the process of decision-making seeks to find the alternative that gives the best value of the objective function, subject to whatever constraints are present. This book identifies the ways poor decisions are made and highlights relatively common situations where decision-making processes: overlook relevant alternatives, such that the most appropriate alternative is not included in the choice set; adopt poor criteria to choose amongst alternatives; or ignore relevant constraints (e.g. political constraints).

Hardaker et al. (2004) noted that the fundamental question concerning the role of formal methods of decision analysis is whether, after leaving aside much of the complexity of the real decision problem, the decision-maker will be left with a problem that is sufficiently:

1. simple to be amenable to systematic analysis, and
2. similar to the real situation that an analysis will help decisions.

This reasoning implies that if so much of the complexity of a real decision problem is put aside to enable analysis, that the remaining scenario is too different from the actual situation to aid choice. This may be particularly true when decisions affect the behaviour of complex social-ecological systems, with their many interactions, positive and negative feedback loops, and multiple sources of heterogeneity. In this kind of setting, the models used to assess the outcomes of decisions can only provide a rough approximation to reality.

A person might use a simple assessment of costs and benefits to evaluate whether to build a swimming pool, or spend the same money on a tennis court, or a home theatre. She might evaluate all of the expected benefits and costs of each option, as they affect her. Which to choose? Whether to do any of them? Maybe just deposit the funds in superannuation instead? These are relatively simple decisions.

The choices about how to adapt to climate change, however, are more difficult to assess because of the complexity of the problem; climate effects are widespread, long-term unevenly distributed across space and time, and unprecedented. Assessments of the benefits and costs of responses to climate change (and similar complex situations) therefore need to be broader than financial implications for private individuals or corporations – requiring assessing all sorts of benefits and costs, regardless of who is affected, including environmental costs and or benefits, and positive and negative effects on society as a whole – and also must accommodate the vast, sometimes irreconcilable, uncertainties of different options under varying future scenarios.

Many novel methods have emerged over the past few decades as analysts have tried to be ever more comprehensive and credible in their calculations of the social benefits and costs of increasingly large and complex problems, such as climate change, and responses to these. The suite of approaches to assessing costs and benefits of complex situations, such as adapting to climate change, is informed by the sources of uncertainty, and how to incorporate learning into decision-making processes. Section 2.1 provides a framework for thinking about the value of information in adaptation decision-making and Section 2.2 show how incorporating elements of adaptive management into decision-making can be used to learn about the costs and benefits of climate adaptation over time.

2.1 Do you need more information to help you compare costs and benefits?

"Jared felt overwhelmed by the choices he needed to make and underwhelmed by the information he had to make them with, and utterly bereft at how little he would be able to do about any of it. He felt like he was probably the last person in the world who should be wrestling with all of this. But there was nothing to be done about it now. He closed his eyes and considered his options."

John Scalzi (The Ghost Brigades)

Suppose Jared is thirsty and could drink either tea or coffee. Jared prefers tea. It seems obvious that Jared should have a cup of tea. Some decisions are easy. More information wouldn't change his mind. For many other decisions, however, it is less clear whether more information would affect the outcome of a decision. Would Jared's choice be any different if the tea was Earl Grey? What if he was told there are additional health benefits from drinking coffee? Perhaps this might affect Jared's choice if he was told, for free, by a friend, but would we recommend that Jared visit his doctor to find out? What about an investment in medical research?

Macauley (2010) summarizes a few main points from decision theory about the value of information in the context of climate adaptation.

1. Not all information has value and perfect information is often not worth the cost of acquisition.
2. Information is less useful if no action can be taken in response.
3. Information may have value if an action is deliberately not taken.
4. An increase in information may not reduce uncertainty but may still be worth acquiring

The first three of these make most sense intuitively. Macauley (2010) notes that people routinely make decisions with information which is less than perfect and balance the chance of making a mistake against the cost of information. In the above example, the cost of new medical research will be greater than the benefits from drinking tea or coffee, and anyway, by the time the results are in, morning teatime will be over. If research suggests that tea is healthier than coffee, but only coffee is available, then this information has little value because you can't take any action in response. Likewise, if you drink tea regularly and then read that tea is healthier than coffee, it will not appear to others that you have changed your behavior, but if you deliberately decide not to switch to coffee drinking as a result, then this information has value. The idea that even though information may not reduce uncertainty it may still be worth acquiring is a little harder to understand intuitively, but if we think about cases where additional scientific research raises more questions than it answers, we can see that even information that subjectively increases our feeling of uncertainty might still have value.

To assess the value of climate adaptation, it can be helpful to frame the decision about whether or not to invest in getting more information in economic terms (Macauley 2010). For example, Neumann and Hudgens (2006) describe an example of cost estimates for coastal protection against sea level risk in California, in which the cost to protect against a 50 cm rise in sea level was estimated as $200 million, but for a 1 m rise in sea level it was estimated as $1.5 billion. Clearly for this decision problem, investing in more information about sea level rise has the potential to save a great deal of money.

Similar to some uses of sensitivity analysis and scenario analysis, an information gap analysis can be used to help assess whether more information might help make a better decision. You can use an informal information gap analysis to think about whether more information is likely to change your decision. This can help you avoid spending time and resources to find out something that would not be very likely to change the outcome. Any comparison of costs and benefits depends on the information available about the alternative actions under consideration. If we are serious about trying to consider all the relevant sources of costs and benefits, we also need to consider the costs and benefits of seeking more information — those likely to be relatively small or negligible can be reasonably ignored in the analysis[2].

[2] A useful heuristic for informing or guiding decisions about whether to invest time and money into improving understanding of the spread, accuracy or precision of information in order to make a decision is provided in the paper "The worth of a songbird" available at: http://www.nusap.net/downloads/funtowiczandravetz1994.pdf (accessed 20 April 2016)

A guided information gap analysis provides a structured process for examining a decision-making process in order to assess whether more information is needed at any stage. Any decision-making process can be characterized using a generic set of steps, for example Randall et al. (2012) considered how different frameworks manage uncertainty at each stage.

1. Problem formulation
2. Generate alternatives
3. Compare alternatives
4. Apply decision criteria
5. Implement
6. Evaluate

Think about the information you have available for each stage in your decision-making process and identify points where more information is likely to change the outcome. This can include thinking about whether more information would help you frame objectives and choose selection criteria differently, whether more information is needed to help you compare costs and benefits of various types, and whether converting alternative metrics or proxies for non-market values into monetary terms would change your decisions.

As an example, for risk management decision-making specifically, the National Emergency Risk Assessment Guidelines (October 2010) list of the stages in a risk management process provides a fairly generic structure. The diagram below includes the critical question, "Would higher confidence result in a different decision being made?" Only if the answer to this question is "yes" would a more detailed risk analysis be suggested (Figure 1).

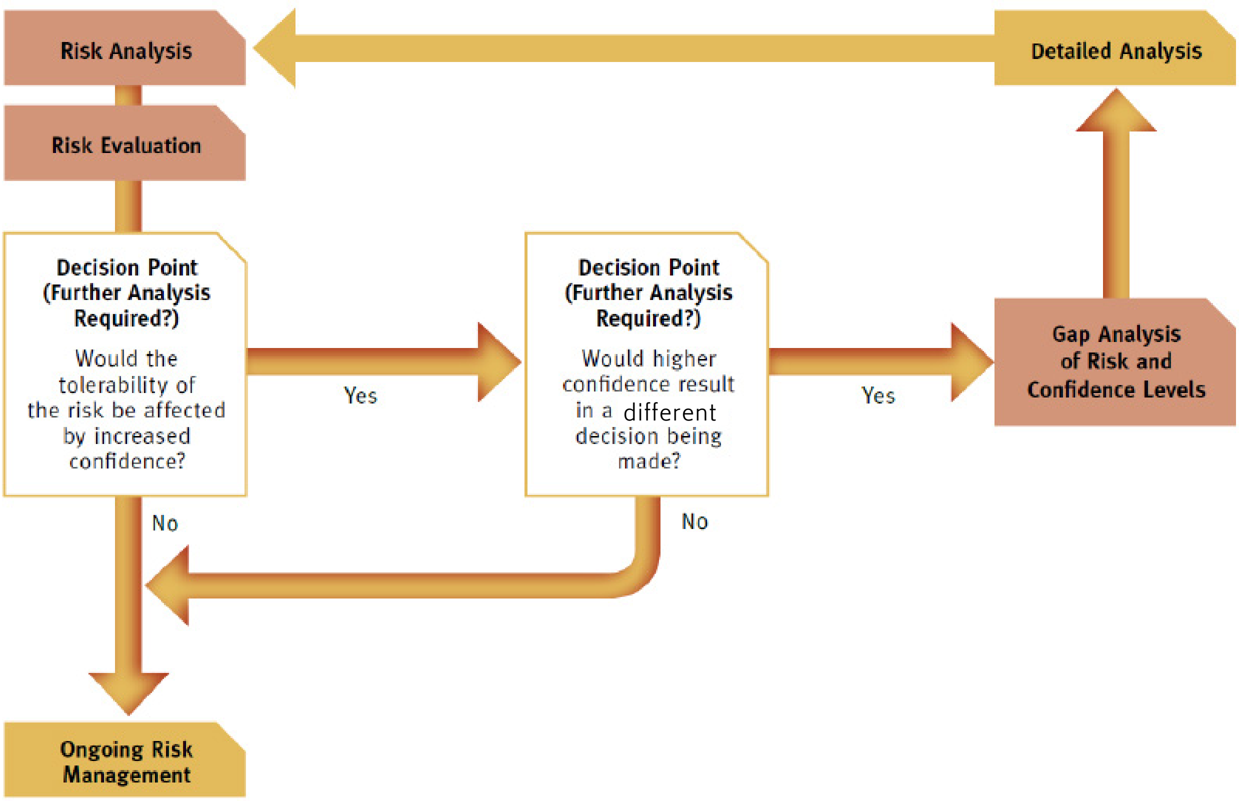

Figure 1: Diagram of an information-gap assessment process for risk management decision-making. Source: NERAG 2010, © Commonwealth of Australia (National Emergency Management Committee).

2.2 Cost-Benefit Analysis and Adaptive Management

Randall et al.'s (2012) Practitioner's Handbook used two big ideas to demonstrate how different decision-making frameworks seek to take into account the costs and benefits of alternative interventions in situations where these are uncertain. They note that the big idea behind Cost-Benefit Analysis is that if we repeatedly implement projects and policies we think are likely to have benefits that exceed costs, then we will end up better-off. The big idea behind Adaptive Management is that we don't know enough about which projects and policies are likely to have benefits that exceed costs and that we are concerned about committing to action that might lead to large costs, and that therefore we need to encourage learning that helps to improve the management of projects and policies, and limits exposure to risk.

Cost-benefit analysis (CBA) and Adaptive Management (AM) form two broad categories of decision-making approaches for either end of a spectrum of types and severities of uncertainty (Figure 2). The 'CBA' end of this spectrum includes static decision-making approaches such as traditional cost-benefit analysis and cost-effectiveness analysis, the Investment Framework for Environmental Resources (INFFER), and forms of multi-criteria analysis. The adaptive management end of the spectrum categorises decision-making frameworks that recognise and acknowledge the presence of all three sources of uncertainty (Figure 1) and emphasize the importance of learning about the system and its dynamics.

Randall et al.'s (2012) 'Practitioner's Handbook' outlines the advantages and disadvantages of various approaches for dealing with uncertainty in climate adaptation decisions. In particular, the book emphasizes the importance of explicitly considering the approach and assumptions of your decision-making to different sources of chance, of which there are three classified in the book "Risk and Precaution" (Randall 2011). The sources of uncertainty in decision-making are (1) outcomes are generated by a random process, (2) we do not understand the system that generates outcomes, and (3) the system that generates outcomes is itself changing. In all situations, all three sources of chance would be present to some degree. It is clear, however, that some decision-making approaches assume simpler forms of chance.

If we had to identify a point where you would distinguish between CBA and AM approaches, it would probably be in the middle of real-options analysis; where approaches to the left compare the costs and benefits of, for example, waiting another year before taking action, and approaches to the right that identify decision thresholds or triggers that would initiate that action when those triggers are observed down the track. Further information about each of the approaches presented in Figure 2 is provided in Section 2.1.

The approaches to assessing costs and benefits presented above (Figure 2) all provide guidance on structuring problems and assessing intended outcomes of proposed options, including the status quo. These all do so based on whether the options lead to a net benefit in social wellbeing or not, with some assessments only using a single measure of social net benefit and others using multiple measures that reflect the plurality of values important for human wellbeing.

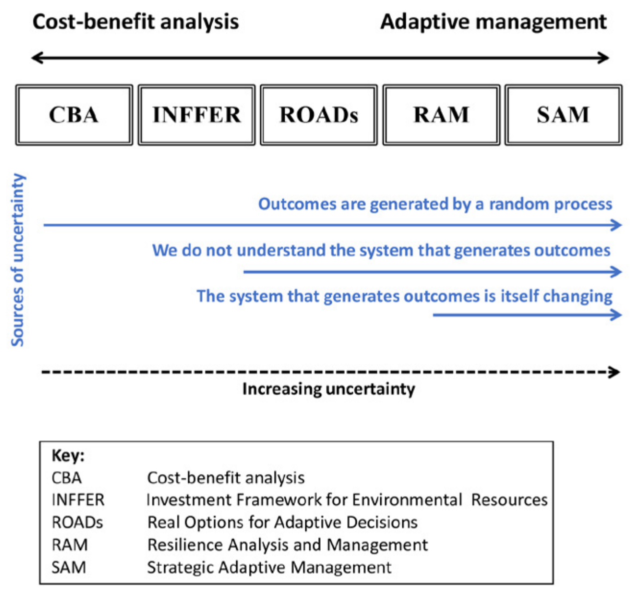

Figure 2: Meta-framework of decision-making approaches suited to dealing with different forms or severities of uncertainty. Source: Adapted from Randall et al. 2012.

Assessment of costs and benefits of adaptation are also likely needed at each of the stages of the 'idealized' decision-making cycle (Figure 3), often by different people, and for different purposes. For example, the initial stage of the decision cycle involves characterizing the difference between the 'real' and the 'ideal' (i.e., problem formulation) by developing an understanding of the current situation or baseline scenario (which involves estimating the costs and benefits of unavoidable climate change) and formulating preferences or objectives (and associated decision-making criteria) to assess alternative outcomes. Whereas the third stage of 'comparing alternatives' will involve identifying and appraising, qualitatively or quantitatively, the costs and benefits of specific options or actions for a particular problem over time. The final stage of 'monitoring, evaluation and learning' involves the difficult aspects of developing and investing in the capabilities, tools and processes required to underpin adaptive learning which is fundamental to decision-making in situations characterized with uncertainty.

It is therefore vital to think about how to support comparisons of costs and benefits at each of these stages. Hinkel and Bisaro (2014) provide a diagnostic approach and guidance on what to do and how for each of these stages.

There are variations of this cycle and numerous guidelines and resources that inform how to plan and undertake adaptive decision-making cycle (see Table 1).

In the following sections we will explore important implications of different types of uncertainty on approaches to quantifying and assessing costs and benefits of climate impacts and adaptation responses. We will provide guidance on how to structure your adaptation problems and how to decide what type of assessment will meet your needs. The sequence of the sections below loosely follow, from left to right, the categories of approaches to assessing costs and benefits in Figure 2.

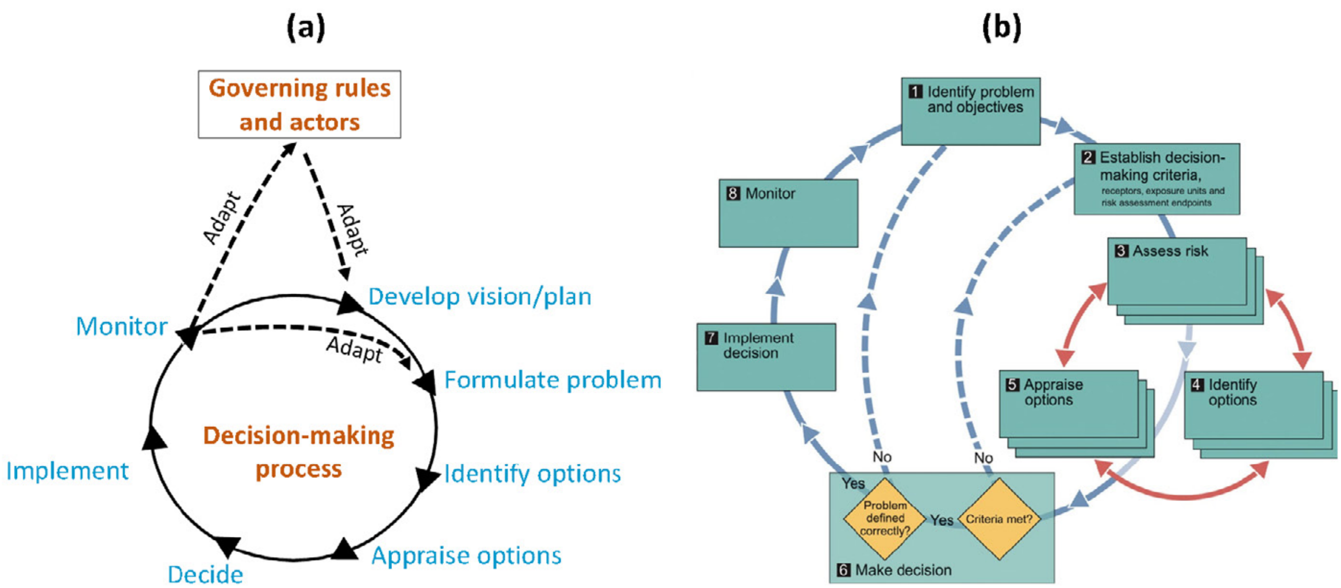

Figure 3: General stages of the (a) decision-making cycle / process or rational planning model (Taylor 1998) and a well-known variation of this (b) developed by UKCIP which emphasizes the iterative and adaptive nature of this cycle in highly uncertain and risky contexts (Willows and Connell 2003).

3 Traditional economic assessment approaches (cost-benefit analysis, cost effectiveness analysis and multi-criteria analysis)

Economic analyses aim to understand and inform the trade-offs in the efficient allocation of scarce resources amongst competing demands. The trade-offs are evaluated on the basis of the value or importance of the resources to individuals and society. The value is determined by social, environmental, cultural and economic factors and requires the use of plural measures of value (e.g., multi-criteria analysis) in order for these values to be effectively and legitimately considered in decisions that inevitably result in some benefiting and others losing out. These dimensions of value, their plurality, and how to consider them in decision-making are explored in Section 6.

Most applications of cost-benefit analysis limit their measures of value to those expressed by individual preferences, with the total value of any resource being the sum of the values that individuals place on its use. Individual preferences can be expressed in two ways, willingness-to-accept (WTA) and willingness-to-pay (WTP). WTA is the minimum payment that the owner of a resource is willing to accept for its use. WTP is the maximum amount a consumer is prepared to pay for using the resource. In the context of climate adaptation, WTP measures the maximum people would be willing to pay to avoid a particular climate impact by adopting adaptation strategies, while WTA measures the minimum people would be prepared to accept, as compensation, for living with the impact.

Financial costs are only one aspect of economic cost. It is essential to take into account the value of the opportunities foregone ('opportunity costs') as well as the costs and benefits experienced by people more broadly ('social' costs and benefits). The economic value of a given climate change impact is the total value that society places on the foregone benefits of the impacted resource stocks and net flows of any potential economic benefits of the climate change impact. Similarly, the economic cost of an adaptation option is the total value of the forgone benefits of the resources used for that adaptation option, that is, the value of the resources that were diverted from alternative productive uses to adapt to the climate impacts (Marsden Jacob Associates 2004).

These resources are measured in terms of the value of the next best alternative to which they could have been applied, i.e. their opportunity cost. Economic costs therefore differ greatly from financial or accounting measure of cost that only measure the financial payments made for goods and services. The economic costs and benefits include these financial costs and benefits plus the social costs and benefits which are not reflected or accounted for by markets because they often cannot be valued directly in monetary terms[3] There are three economic criteria for informing assessments of interventions in terms of their net impact on social wellbeing: net social benefit, benefit-cost ratio, and net social benefit per unit of investment (Box 1).

[3] External costs are costs that are external to the decision maker and which are not reflected in market prices. Many of the environmental, health and social impacts of climate change will fall into this category. External costs (or benefits) are examples of market failure.

Box 1: Criteria for measuring the net effect of programs or projects on societal wellbeing

There are three main ways (criteria) of expressing the results of economic assessments of costs and benefits, which unfortunately can often lead to different recommendations about whether the proposed investment should proceed or not.

1. Net Social Benefit is the sum of all the benefits less the sum of all the costs (all expressed as the present day equivalent of values). The norm would be to choose whatever project had the greatest NSB and to reject any project where NSB is negative.
2. The Benefit-Cost ratio is the sum of all the benefits divided by the sum of all the costs (all expressed as the present day equivalent of values). Again choose whichever project gives the highest ratio and reject anything with a ratio less than 1.00.
3. The Net Social Benefit per unit of investment, which is estimated by dividing the NSB (criterion 1) by the total capital investment made. This measure addresses the issue that the first criterion can favour larger projects and doesn't focus on relative effectiveness in how capital is deployed.

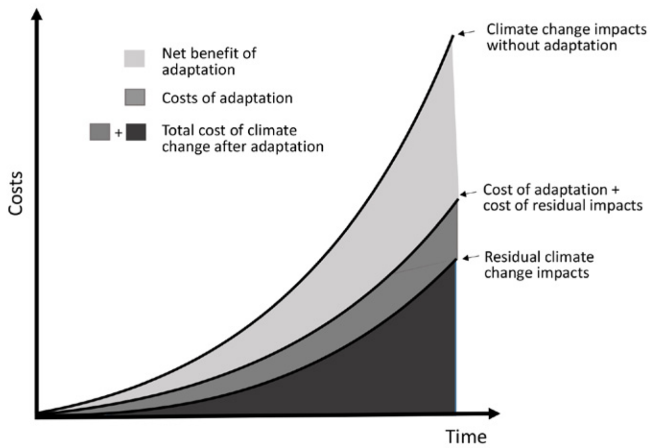

Figure 4: Illustrative example of baseline future impacts under climate change compared with future impacts after adaptation. The lightly shaded area between the upper two curves is the net benefit of adaptation; the size of which is clearly heavily influenced the expectations/projections of the magnitude of future climate change impacts without adaptation. Source: Adapted from Dittrich et al. 2016.

So, if the objective is to produce estimates of the social net benefits of adaptation to specific climate change impacts to inform choices between different adaptation options, this requires a baseline or reference scenario to be specified. The baseline (or reference scenario) is the future impacts (and associated costs) of climate change in the absence of adaptation; the effect of the adaptation response is to reduce the impact of climate change on the system or sector; and the reduction in the cost of the impact, after including the costs of adaptation, represents the net benefit of the adaptation response (Figure 4). This is the basis by which different adaptation responses can be compared.

3.1 Guidelines for incorporating traditional economic assessments into decision-making

Schuck (2014) suggested that traditional approaches to assessing costs and benefits, such as CBA, are "simply rationality in the service of sound policy," but noted that there are genuine technical, conceptual, and normative objections to more narrowly framed cost-benefit analysis approaches. In particular, cost-benefit analysis is only useful for evaluating interventions where other factors can be held constant and not where changes are significantly large to create substantial market and non-market effects, so all other factors cannot be assumed constant. Schuck (2014) argued that a well-conducted cost-benefit analysis can be legitimate, desirable, and an indispensable technique for assessing policies and projects, and that criticisms should focus on the competence, transparency, moral scrupulosity, and persuasiveness of a given cost-benefit analysis. To this end, Schuck (2014) provided guidelines for incorporating cost-benefit analysis into policy decisions:

1. Policy-makers should intervene only when it will correct a significant market failure[4].
2. A program should maximize net benefits and also be cost-effective.
3. Cost-benefit analyses should be conducted for different levels of benefit, e.g. it may be much more costly to increase benefits a little more at high levels of benefit than at lower levels of benefit.
4. A program should be target-efficient, i.e. resources are allocated where they can do the most good.
5. A policy may be cost-ineffective because it uses the wrong tool.
6. Special efforts must be made to identify 'invisible victims' and consider their interests in the analysis.
7. Cost-benefit analysis should be used to retrospectively analyse the effectiveness of existing policies, not just proposed ones.
8. Ending a failed policy is a kind of policy success.
9. Policy-making demands appropriate organizational analysis.
10. Policy assessment requires an appropriate time-frame.
11. Policy assessment requires competent and objective assessors.
12. The well-designed randomized controlled experiment is the gold standard for assessment, but extremely rare in practice.
13. Policy assessments must take most of the existing social and institutional context as given.
14. Avoid the 'Nirvana fallacy' i.e. viewing the policy choice as if it were one between an ideal program and the existing, flawed one.

3.2 Challenges to assessing costs and benefits of adaptation

The climate adaptation context presents many challenges for decision-making. It is important to explicitly consider these challenges in evaluating the process you use to assess costs and benefits.

Randall et al. (2012) used the Adger et al. (2005) description of an ideal decision support tool as the basis for identifying some of the challenges people will face when assessing the costs and benefits of adaptation. Adger et al. (2005) argued that an ideal decision support tool for climate change adaptation would be effective, efficient, equitable, and legitimate. *Effective* decision support achieves its objectives without unintended consequences or perverse outcomes. *Efficient* decision support maximizes social net benefits. *Equitable* decision support considers the distribution of costs and benefits and may weight or constrain decisions based on ethical considerations, such as the needs of future generations and the responsibility for decisions and impacts. Legitimate decision support has the approval of those who are affected by the decision.

With this in mind, Randall et al. (2012) identified some of the challenges of assessing the costs and benefits of climate adaptation. Stakeholder engagement is vital for all four criteria of ideal decision support. For example, a decision-making process is unlikely to be considered as legitimate without involving interested and affected stakeholders in the decision-making process. And since climate impacts are often widespread and unevenly affect many diverse stakeholders across jurisdictions and decision-making levels, it is both difficult and important to try understand and accommodate these diverse effects and interests. Climate adaptation decisions also affect the behavior of complex social-ecological systems, and the models used to compare the outcomes of alternative decisions cannot capture all the complexity of non-stationarity, thresholds, or non-linear feedbacks. Climate adaptation

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[4] Market failure refers to situations where markets are not able to realize efficient allocations of goods and services. Market failures are often associated with the existence of externalities (good or bad), public goods, information asymmetries, principle-agent problems, and non-competitive markets (i.e., where a few monopolize the market). These examples are briefly explained in the Glossary of Terms. The existence of a market failure is often the reason for governments, supra-national institutions (e.g., UNFCCC), or self-regulatory organizations to intervene in a particular market. Externality (external costs or benefits): Effects of a transaction which are incurred by those other than the buyer or the seller.

decisions therefore need to take into account all three sources of chance identified by Randall (2011) (outlined in Section 2). Because decision outcomes will play out over long periods, it is difficult to foresee all possible consequences and including elements of an adaptive approach to decision-making is essential in this context. This means it is important to consider actions that can help you learn about the system that generates outcomes. When we don't understand the system that generates outcomes and the system itself is changing, we need to consider carefully what constitutes effective and efficient decision-making. This means paying careful attention to the nature of objectives, and particularly to the possibility of irreversible unintended consequences or perverse outcomes, and the importance of taking into account values that are not currently priced by today's markets when assessing social benefits and costs.

Adaptation actions are also often embedded within responses to other drivers of change, making it difficult to separately cost the climate component of actions and this means adaptation assessments must be integrated within more holistic planning (OECD 2008). And finally, some consequences or impacts of climate change will be substantial, even catastrophic in magnitude or rate and will make the assumptions of marginality[5] and 'all else constant', which underpin economic valuation and assessments, unjustifiable (Fisher and Le 2014).

[5] Marginal analysis relates to the important focus of all economic analysis to determine the 'ideal' level of any activity (investment, production or resource allocation). The ideal level of an activity should be judged by examining the benefits and costs of the last (or marginal) unit. It also emphasizes that economic analyses focus on assessing the costs and benefits of a change in the status quo or business as usual. Marginal analyses recognize the influence / role of scarcity in setting exchange value. For example, diamonds command a higher market price than water. The first units of water consumed are of very high value, being necessary for survival. Because water is abundant, however, additional units are used for activities with less marginal utility and are therefore of less value. The marginal utility of the next unit of abundant water is thus lower than the marginal utility of relatively scarce goods such as diamonds.

4 Discounting in the context of large, long-term and highly uncertain change

Cost-Benefit Analyses *"...are ill-equipped to handle issues involving uncertainty about crucial parameters evolving over long periods of time. Yet there is no well-developed alternative. In analysing such problems we are pushing economic analysis to its limits. Economists lack an analytical procedure to deal with problems involving unforeseen outcomes... While such basic problems remain unresolved,* ***any choice of discounting procedure to assess long-term risks such as climate change will yield some implications that are intuitively unappealing or inconsistent with observed market outcomes****. Economists can help to define the issues, but it is unlikely that economics can provide a final answer. Ultimately, the response to climate change is a social and political choice..."* (Dixit and Pindyck 1994)

4.1 What is discounting?

Most people's behaviour indicates that they prefer to have the purchasing power of a dollar today, or very soon, rather than in the distant future (Sunstein and Weisbach 2008). A dollar received today is generally considered more desirable than a dollar to be received in 5, 10 50 or 100 years (even after allowing for inflation over that period). Interest paid on savings (i.e. money not spent on consumption now) provides an incentive for individuals to defer the satisfaction or gratification that can come from consumption today.

Discounting is the practice of adjusting the values of benefits and costs of a project, activity or program into a comparable unit at a particular point in time, usually the present (termed "present values"). This is considered by many to be important when evaluating the effectiveness of projects, programs and policies in all areas, including the environment, because these activities generally involve incurring costs in the present in return for benefits in the future.[6] The practice of discounting therefore allows an assessment of how the expected returns of the investment compare against alternatives, with the fundamental alternative being the return available from putting the money in the bank (i.e., which is the opportunity cost of the investment).

4.2 How is discounting done?

Discounting uses a discount factor normally set to a value of 1 for costs and benefits experienced today, and is less than 1 for costs and benefits experienced in the future. Therefore, most simplistically, the present value of a future benefit or cost is the value of the future benefit or cost multiplied by the discount factor.

The rate at which the discount factor (*df*) declines each year is determined by the discount rate (*dr*). The relationship between the discount factor and the discount rate depends on the assumptions, expectations, or observations about how individuals or communities value things today compared with the future. The standard approach is to assume the discount rate is constant and positive which implies an exponentially declining discount factor[7].

[6] But sometimes there are short term benefits with long term costs e.g. mining with subsequent remediation, or nuclear-powered energy with long-term storage costs. So, whether the costs precede, or follow, the benefits, it is crucial to have all values expresses on current day equivalents, and that's what discounting achieves.

[7] The relationship between the discount factor and the discount rate is represented algebraically by df = 1/(1+dr)t. The discount factor or discount rate can be used to determine futures values (e.g., Future Value = Present Value * (1+dr)t) and present values (Present Value = Future Value / (1+dr)t), where 't' is time measured in years.

As an example, if the discount rate is assumed to be 10% per year, then the discount factor today is 1, 0.62 in year five, and 0.38 in year 10; implying that a benefit of $100 in ten years is equivalent to $38 today. This assumed exponential rate of discounting is depicted for $100 at a discount rate of 2% and 10% in Figure 5 (curves '2% Exp' and '10% Exp'). The key messages from this are that a positive discount rate means future cash flows are valued less than cash flows today and a constant discount rate means future values are considered to decline exponentially[8].

Different approaches to discounting have been developed to accommodate different observed phenomena regarding time preferences of individuals and communities. Examples include hyperbolic discounting (Quiggin 2008), gamma discounting[9] (Laibson 1997), prescriptive discounting based on an "intergenerational discount rate" (Weitzman 1998), and the use of negative discount rates (Hallegatte 2008) have been proposed. Hyperbolic discounting, for example, allows the rate to decline with time (df = 1/(1+dr*t), to reflect the observed behaviour of individuals' of diminishing impatience (see curves '2% Hyp' and '10% Hyp' in Figure 5). The key factors influencing the value of the discount rate are discussed in section 6.3 below.

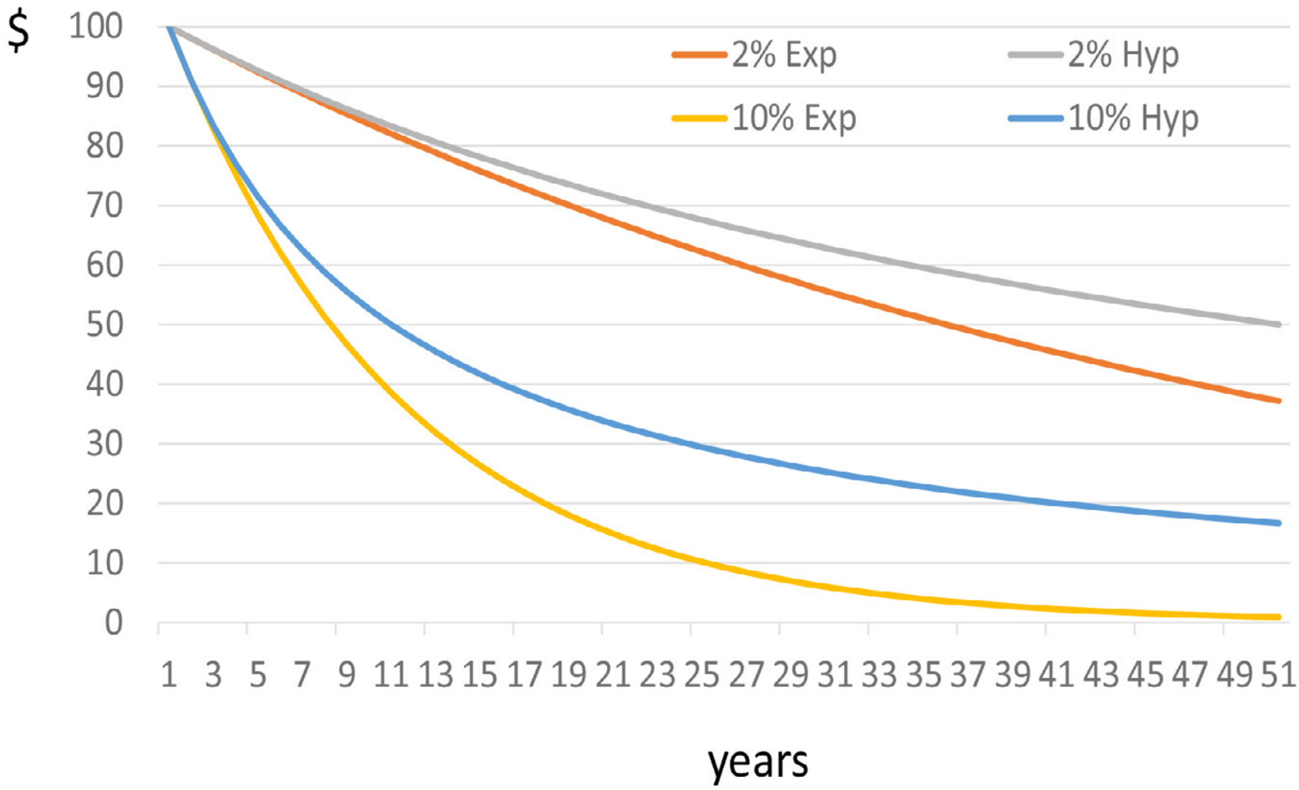

Figure 5: Effect of discount rate on present values of future benefits. Source: Developed by authors.

[8] Discounting is simply the reverse of compound interest. If the interest rate is 10%, $38 invested today would grow to $100 in 10 years. If my "rate of time preference" is 10% p.a., then I should be indifferent between $38 now and a guaranteed $100 in 10 years.

[9] Where the possibility of declining consumption discount rates (due to the possibility of catastrophic change) is accommodated through accounting for the uncertainty and ambiguity in future events.

4.3 Choosing a discount rate for assessing costs and benefits

There are many factors that influence the choice of discount rate and the relationship between the discount rate and the discount factor over time.

4.3.1 Social discount rate or market discount rate?

The first important decision is whether to use a social discount rate or the market/private discount (interest) rate. The two rates are generally, and have historically been, very different. The reasons for this are provided in Section 4.5.

The choice depends on the type of investment being evaluated and whether the benefits and costs are predominantly private or public. Most public policy and investment decisions involve public finances (sometimes co-invested with private funds) generating public benefits by providing goods and services such as roads, nature conservation, and water. In the case of climate adaptation, whether privately or publicly funded, there will generally be private and public benefits and costs due to the cross-scale nature of climate change. In such situations there are at least three arguments why the social rate of time preference (social discount rate) is to be preferred to market interest rates for evaluating investments that affect public / societal interests:

1. **Market imperfections.** Market prices generally give misleading signals of values (i.e., do not reflect the true social opportunity cost of the resource) because of distortions in the economy such as pollution (climate change), taxation, and imperfect information.
2. **Super-responsibility**. The government has a responsibility to both current and future generations, and markets do not reflect the preferences of generations in the distant future.
3. **Isolation argument**. Individuals may be willing to join in a collective savings contract, even though they have been repeatedly observed to be unwilling to save as much in isolation (i.e., individuals' choices as consumers differ from those made as a citizen in a community). An altruistic person may rationally encourage society to invest in anything that generates a positive return, even at say 4%, even though personally they wouldn't invest in anything that returns less than 8%.

If the investment is a private investment of private funds at the local scale with limited impact on public assets (including ecosystems), then a market-based discount rate is appropriate[10].

Difficulties in selecting a discount rate arise in situations where public and private funds are used in projects, where each takes on a different level of risk, requires different returns on investment (often approximated by the best forgone return of the investment), and is interested in different benefits (public versus private). Some suggest the private and public components of this investment should be assessed separately, using different discount rates that reflect the different opportunity costs and objectives of the investments. Others suggest this not only complicates the analysis but is almost impossible due to the interdependencies between the private and public aspects of these investments. In such situations, it is more transparent to apply a single discount rate and to make explicit important ethical and environmental implications of the project for deliberation in a multi-criteria assessment framework.

[10] If society uses a discount rate that is "too high" then it will make less than adequate provision for future generations (it will fail to invest in projects that would have been acceptable at lower discount rate. But if Society uses a discount rate in public investment projects that is below the rate required for private investments, it will divert resources from the private sector where the capital would be used efficiently, to less capital-efficient public projects, meaning the overall portfolio of projects will be less capital-efficient.

4.3.2 Should the discount rate be positive or negative, big or small, constant or changing?

A positive discount rate is commonly justified for two reasons. Firstly, people generally prefer to have good things earlier rather than later. Secondly, capital is productive and so savings can be expected to yield positive returns that allow higher consumption in the future than today. And since consumption is widely expected to increase over time, along with the observation that the utility derived from each additional unit consumed diminishes, this implies that additional consumption in the future is less valuable than it is today and so should be discounted.

In some economic analyses of climate change impacts, mitigation and adaptation, economists such as Nordhaus (2007), Tol (2010), Tol and Yohe (2006), and others, have tended to apply discount rates based on market interest rates, which have averaged around 6% (excluding financial crises) over time. These approaches entirely ignore the reasons provided in Section 4.4 for why a market-based discount rate is inappropriate for evaluating any investment which has implications for public interests or assets (including the environment) over the long term. Additionally, these proponents of a large discount rate ignore the effects of uncertainty. Weitzman (1998) shows that when uncertainty is taken into account the certainty-equivalent average consumption discount rate over 100 years drops from 6% to 2%. Weitzman (2009) goes further to show that accounting for "unknown unknowns" by assuming the probabilities are themselves uncertain, takes this rate even lower and closer to 1.5%.

There is growing evidence that natural capital is being rapidly and irreversibly lost and will negatively impact on the consumption of the services provided by natural capital and human wellbeing and cannot be offset by simply saving more or investing in physical or human capital. These impacts, although currently mostly from human population growth and economic development, are likely to be enhanced in uncertain ways by climate change. These arguments provide support for the use of extremely low, declining, or even negative discount rates where a project, policy or program negatively impacts on the environment (Blignaut and Aronson 2008).

There is also the ethical argument that the measure of a person's utility should not be reduced simply because they will exist in the future. Irrespective of this dimension, there is a credible argument for discounting future utility because there is a small, but ever-present, possibility that human civilisation will cease to exist (due to an asteroid striking Earth or a nuclear accident, for example) (Stern 2006; Hepburn 2007).

Finally, in general, the appropriate social discount rate is not constant over time, but is a function of the expected future rate of growth in consumption. For instance, if it were known with certainty that future consumption growth will be cyclical, then the appropriate social discount rate should vary to reflect those cycles. There is also increasing interest in using a hyperbolic discount rate, as briefly shown in Section 4.2. This however, is criticised by many for not being appropriate to use as a social discount rate as it more accurately reflects individuals' commonly observed behaviour of diminishing impatience (Hepburn 2007; Hepburn et al. 2010). In most instances, however, the discount rate is assumed to be constant.

4.3.3 Examples of discount rates used in the literature and practice

The Stern Review used an averaged consumption discount rate, s, of 1.4% per annum and consequently recommended more rapid reductions in greenhouse gas emissions than had been the case until then (Stern 2006). This was estimated based on: a utilitarian ethical perspective that placed as much weight on future generations as the present; consideration of the exogenous risks of catastrophic impacts on humanity by some disaster; and regionally sensitive rates of growth in consumption (averaged at 1.3% per annum).

The current trend by some governments around the world, motivated by concerns about intergenerational equity, is to use differential declining rates. The UK Treasury, for example, uses a 3.5% discount rate for the first 30 years and then a 3% rate for the next 40 years, when evaluating public policies and projects (Hepburn 2007; Hepburn et al. 2010).

5 Sensitivity analysis

A sensitivity analysis can be used to investigate the consequences of changes and errors in the parameter values and assumptions used in models, including the investigation of models used to support decision-making. Pannell (1997; 2016) provides an overview of sensitivity analysis, including a list of many of its uses, as shown in the following list from Pannell (2016) and for which the details can be found at: http://dpannell.fnas.uwa.edu.au/dpap971f.htm (accessed 20 April 2016).

Uses of sensitivity analysis:

1. Decision-making or Development of Recommendations for Decision-makers
   - **1.1** Testing the robustness of an optimal solution.
   - **1.2** Identifying critical values, thresholds or break-even values where the optimal strategy changes.
   - **1.3** Identifying sensitive or important variables.
   - **1.4** Investigating sub-optimal solutions.
   - **1.5** Developing flexible recommendations which depend on circumstances.
   - **1.6** Comparing the values of simple and complex decision strategies.
   - **1.7** Assessing the 'riskiness' of a strategy or scenario.
2. Communication
   - **2.1** Making recommendations more credible, understandable, compelling or persuasive.
   - **2.2** Allowing decision-makers to select assumptions.
   - **2.3** Conveying lack of commitment to any single strategy.
3. Increased Understanding or Quantification of the System
   - **3.1** Estimating relationships between input and output variables.
   - **3.2** Understanding relationships between input and output variables.
   - **3.3** Developing hypotheses for testing
4. Model Development
   - **4.1** Testing the model for validity or accuracy.
   - **4.2** Searching for errors in the model.
   - **4.3** Simplifying the model.
   - **4.4** Calibrating the model.
   - **4.5** Coping with poor or missing data.
   - **4.6** Prioritizing acquisition of information.

Pannell (2016) provides an overview of the uses and methods available to conduct a sensitivity analysis. In any model, the parameters used for prices, costs, benefits, and so on, are uncertain, so sensitivity analysis can be used to help inform decisions or recommendations by providing information about how sensitive model outputs and optimal solutions are to changes in parameter values and circumstances. For example, a sensitivity analysis can help show how much worse things could be if changing circumstances were to be ignored.

5.1 Scenario analysis

Scenario analysis provides a framework for exploring the uncertainty around the future consequences of a decision[11]. Scenario analysis is particularly useful when decision-makers face forms of uncertainty that are 'uncontrollable' or 'irreducible' and can be used to improve understanding of key uncertainties, incorporate alternative perspectives, and increase the resilience of decisions to potential shocks or surprises (Peterson et al. 2003). In this way, you can see scenario analysis as a form of sensitivity analysis. A scenario analysis can be used to provide information about possible future states of a system, a better understanding of the conditions under which alternative states could occur, a better understanding of the possible trade-offs represented by different states, identify opportunities for adaptation, and a better understanding of the degree of uncertainty associated with the possible outcomes of alternative decisions (Kaya et al. 1999).

Advantages of scenario analysis include its use in investigating the consequences of sources of chance that are not easily amenable to probability calculations. Another major advantage of scenario analysis is its use in communicating with and engaging stakeholders (e.g. Bohensky et al. 2005), although how scenarios are constructed will depend on who is invited to participate, then the diversity of views, values, trust and relative power in situations of consultation or negotiation all need to be considered (Kaya et al. 1999). Scenarios can be constructed at multiple scales to help reveal trade-offs that only become apparent when looking at a problem at a different spatial scale or a longer timeframe (Bohensky et al. 2005).

It is possible to use scenario analysis more or less informally, depending on your needs and resources. An informal process of scenario analysis will often be sufficient to identify the most important threats or risks. It is important not to get too caught up in the details but to reflect on what the key variables are, what you understand and what is unknown about the changing dynamics of the system, and worst-case scenarios that could result without the wrong intervention or none at all.

That said, we can more formally identify the main stages of a scenario analysis approach for decision-making in a complex system, for example, based on Kaya et al. (1999). The first steps are to define and describe the system. Factors to consider include the appropriate scale for describing the system, its boundaries, characteristic processes, and possible alternative states. This will involve describing the relationships between components of the system, including identifying important causal relationships and positive and negative feedbacks. The next steps involve describing desirable and undesirable states of the system, such as those that support valued ecological and economic processes, and then evaluating the threats to the desirable states by examining external influences and threats or risks. The final steps consider how to mitigate known threats and to promote positive influences. As part of an anticipatory and adaptive approach to decision-making, the system can be monitored to detect new changes from new external influences.

[11] Uncertainty describes the situation where outcomes are likewise definable, quantifiable and random but are governed by an unknown probability function (Knight 1921). Fundamental uncertainty Perrings (2007), also referred to as 'radical uncertainty' or 'irreducible ignorance' Lemons (1998), 'deep uncertainty' Lempert et al. (2003), and 'severe uncertainty' Ben-Haim (2006), is a more severe form of uncertainty that describes situations where not only the probability of an occurrence is not known but the possible outcomes are also not known or are unknowable. Such situations are relatively common in complex systems comprised of self-organising and adaptive structures.

6 Assessing costs and benefits of climate impacts and adaptation options

The practicalities of assessing costs and benefits of climate adaptation (i.e. Stages 3, 4 & 5 of the rational planning model, Figure 3) involve: identifying different types of values affected or relevant to understanding the implications of climate change and adaptation options; understanding the institutional requirements and barriers to recognizing and accounting for different values, and how to deal with these; measuring or quantifying different types of values; and evaluating the relative importance and trade-offs between values. Each of these is explored in the sub-sections below.

6.1 Identifying different types of values affected by climate change and adaptation

The assessment of costs and benefits of climate change or adaptation interventions involves understanding, quantifying and evaluating the effects of these changes on what is valued by stakeholders. Value "…*is the importance, worth, or usefulness of something*" or "*one's judgment of what is important in life*" (The Oxford Dictionary). Valuation is therefore the act of assessing, appraising or measuring value or importance. Values can be motivational, functional, held, intrinsic or ascribed, and each can be associated with individuals or shared by a group or community (Table 2).

Table 2: Different concepts of value and their definitions, which can be shared/social[12] or individualistic

Type of value	Definition
Functional values	Non-preference-based values derived from a quantification of the biological or physical relation of one entity to another, for example, the value of nesting habitats for birds. Such values are free from human preferences and as such are outside the realm of valuation (Brown 1984).
Held values	These are deep first-order values that influence subsequent, second-order (ascribed) values (Brown, 1984). Examples of held values are ideas of justice, identity, sustainability and freedom. These form the conceptual basis for decision-making. These are difficult to quantify and attempts to do so tend to result in valuations that lack legitimacy in the eyes of the public (Vatn and Bromley 1994).
Intrinsic values	Intrinsic values reflect the ethical stance that an object has value for its own sake (Zimmerman 2001)
Motivational values	These are ethical precepts or beliefs that determine the way people select actions and evaluate events. Schwartz's (2012) identified ten universal values according to the motivation or goal that underlies each: power, achievement, hedonism, stimulation, self-direction, universalism, benevolence, tradition, conformity, and security. These are related in conflicting or congruent ways and are assigned different priorities according to the individual and the context (Gorddard et al. 2016).
Ascribed values	Ascribed (or assigned) values are second-order preferences, generally associated with goods or services that individuals are prepared to ascribe relative values to and make trade-offs between (Brown 1984). These are mostly amenable to monetary valuation (Abson and Termansen 2010).

[12] A good summary of shared/social values of ecosystems is available at: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=RBEx5VNe3GY%3d&tabid=82 (accessed 20 April 2016). This resource explains these types of values, how they can or should be accounted for in decision-making, and it provides sources to further information.

All of these value concepts influence how costs and benefits can and should be measured and considered in decision-making. And these values apply not only to goods and services directly used by individuals and societies, but also to the non-use biophysical characteristics of resources and to how resources are or should be allocated.

Each value concept in Table 2 influences how individuals and groups perceive and experience the impacts of climate change, and their preferences for how best to respond to change. Understanding which motivational values prevail or predominate in a community, for example, is critical for understanding expressed visions, problem framings and proposed solutions and for informing how to engage with communities on these issues. For example, is the vision, problem definition or proposed solutions contested, and is this due to differences in deeply-held values or because of conflicts of interest? Are justice and sustainability considered important and valued by the affected stakeholders? Are private and economic values prioritized above public or environmental values? The answers to these questions will influence the vision, the problem definition and solutions proposed by stakeholders.

The remaining values concepts (functional, intrinsic and ascribed) are important at the more pragmatic level of measuring, evaluating and prioritizing costs and benefits. These types of values are experienced, articulated and quantified as social or shared values, economic or monetary values, or purely as functional values. These aspects to assessing costs and benefits are explained in Section 6.1.

6.2 Quantifying costs and benefits of climate change impacts and adaptation

There are numerous challenges in quantifying the costs and benefits associated with changes to physical, human, and ecological resources. To demonstrate some of these challenges, in this section we focus on the quantification of the values provided by ecosystems. The benefits that humans derive from ecosystems are referred to as 'ecosystem services' (see https://www.gov.uk/guidance/ecosystems-services for a thorough overview and associated advice on how to value and consider ecosystem services in decisions – accessed 20 April 2016). Ecosystems are valued for sustaining human wellbeing. These values comprise economic values, ecological values, and socio-cultural values, each of which is explored below (Figure 6). Climate change, and human responses to these changes, will impact on ecosystems and the benefits and costs that people experience from them (see Table 1 for examples). It is therefore helpful to understand the nature of these costs and benefits to inform adaptation responses.

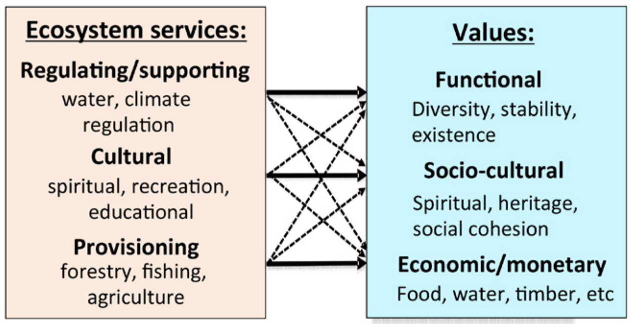

Figure 6: Associations between major categories of values (i.e., functional, socio-cultural and monetary values) and major categories of ecosystem services (i.e., provisioning, regulating and cultural services). Source: Adapted from Gómez-Baggethun and Martín-López 2015.

Since most ecosystem services have plural values associated with them (Figure 6), it is important that decision-makers are aware of whether the rules (regulations, norms, procedures, methodologies and practices) allow for these plural values to be accounted for in decision-making. Guidance to this assessment of the rules has been provided in Section 6.2 below.

Valuing ecosystem services to prioritise and sequence adaptation options requires understanding of the different types of values derived from ecosystems, criteria for measuring these values, and methods for qualitatively or quantitatively estimating their absolute or relative sizes. These aspects are addressed sequentially for functional (ecological) values, socio-cultural values and economic (monetary) values.

Functional values are what gives ecosystems capacity to sustain ecosystem services over time. These relate to the ecosystem functions and processes on which ecosystem service delivery depends and are typically measured by criteria that reflect an ecosystem's diversity, productivity, stability, and connectivity. Methods for measuring these include: material flow analysis, land-cover flows, and embodied energy analysis to name only three. Further information on these methods and an assessment of their suitability for different purposes is provided in the freely downloadable chapter by Gómez-Baggethun and Martín-López (2015)[13] .

Socio-cultural values are intangible, place-based, and emerge from people's emotions and attitudes toward nature. These values are created in the minds of the beneficiaries of ecosystem services and therefore vary depending on the person. And since these values are often shared they are also influenced by the formal and informal rules that govern the behaviours, norms, taboos and cultural practices of societies or communities (Kenter et al. 2015)[14] . Socio-cultural values are reflected by spiritual and heritage values, social cohesion and sense of community, to name a few. Methods for directly measuring values of cultural ecosystem services are diverse, often context-specific and generally qualitative, because they usually lack any obvious biophysical or monetary counterpart for use as a proxy. In some cases, tools have been developed to quantify cultural services and related values using scores and constructed scales as in the cases of place values and aesthetic values. In other cases, however, quantifying cultural services may be too difficult and demands holistic approaches that may include qualitative measures or even narratives (Kenter et al. 2015; Gómez-Baggethun and Martín-López 2015). See footnotes 11 and 12 for links to further information on these methods and an assessment of their suitability for different purposes.

Economic values

The assignment of monetary values when estimating the costs and benefits of the impacts of climate change or adaptation options, requires three assumptions to be met regarding the meaning of value:

1. value can be ascribed (Table 2)
2. value should be measured at the margin[15]
3. value can be expressed in terms of exchange[16] .

These three assumptions are generally well founded in the context of market goods, but do not necessarily hold true when applied to non-market goods and services (Vatn and Bromley 1994). Where monetary values can be quantified (i.e., when the above three assumptions are fulfilled), the Total Economic Value (TEV) framework developed by Krutilla (1967) is a useful structured approach to ensuring all relevant values are identified and accounted for (Figure 7). Extensive lists have been collated of the various

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[13] Further information is available at: https://www.researchgate.net/publication/281710952_Ecological_economics_perspectives_on_ecosystem_services_valuation (accessed 20 April 2016).

[14] A user-friendly version of this is available at: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=RBEx5VNe3GY%3d&tabid=82 (accessed 20 April 2016).

[15] The concept of marginality relates to the important focus of all economic analysis determining the ideal level of any activity (investment, production, or resource allocation). The ideal level of an activity should be judged by examining the benefits and costs of the last (or marginal) unit. It also emphasizes that economic analyses focus on assessing the costs and benefits of a change in the status quo or business as usual.

[16] Exchange value represents the quantity of other goods or services that a given good or service can be exchanged for, if traded in the market. It provides a common unit to express the trade-offs between different factors that contribute to human welfare.

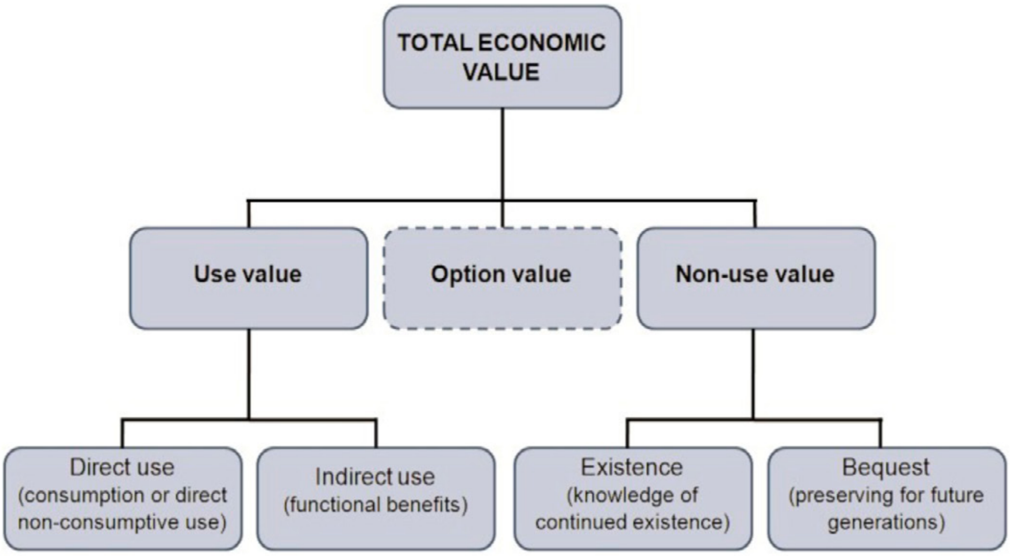

Figure 7: The Total Economic Value framework, accounting for use values, non-use values and option values. 'Option values' are emphasized because they fall under both use and non-use values and are a particularly special and important type of value in context of high uncertainty. Source: Adapted from Krutilla 1967.

estimates of the use values, non-use values and options values associated with different ecosystems in many locations in Australia and globally.

Where goods and services are traded in markets their values can be readily approximated using market prices as a proxy for value [17]. However, many goods and services, particularly those derived from ecosystems, are not traded in markets. The monetary values for these could be approximated using estimates of replacement costs or avoided expenditure, which draw on costs of activities for which market prices do exist. Otherwise, monetary values of these non-market goods and services can be estimated in 'parallel markets' using techniques such as hedonic pricing and travel cost methods or in hypothetical markets using approaches such as contingency valuation or choice modelling. These techniques are all well-developed and there is a plethora of information sources and examples of their application (see Table 1) (e.g., Russell 2001; Turner et al. 2000a, 2000b). However, these are often applied in breach of the three assumptions above or where extremely dubious assumptions are made about these three critical characteristics of economic values.

Alternatively, there are discourse-based and stakeholder-oriented methods such as deliberative monetary valuation (Spash 2008; Wilson and Howarth 2002) or 'deliberative multi-criteria evaluation' (Proctor and Drechsler 2006). These methods encourage stakeholders to express their values through dialogue and scientific information and other expert input can be added to the process (Hermans et al. 2006). Many of these methods integrate stakeholder valuation into a particular decision-making process, so it may be difficult to separate the valuation elements from the outcome. Further information on these methods and an assessment of their suitability for different purposes is provided, as for the ecological and socio-cultural values, in the freely downloadable Chapter by Gómez-Baggethun and Martín-López (2015).

[17] Exchangeability: Exchange value represents the quantity of other goods or services for which a given good or service can be exchanged, if traded in the market. It provides a common unit to express the trade-offs between different factors that contribute to human welfare. But, not all the values associated with ecosystems can be captured with a single metric. Economic valuations are expressions of either hypothetical or real market values and imply potential for substitution, under the assumption that the values of services 'in use' and 'in exchange' are equivalent. This holds true for market goods and services.

The application of the TEV framework to the valuation of ecosystem services, consistent with the assumptions required for their economic valuation, is briefly presented below. It draws upon a simple framework (Figure 8) that links the types of ecosystem services to the forms of value associated with that service, to the benefits provided by that services, through to the form of expression of that value (economic, cultural or ecological). The aspects of ecosystem services that are amenable to economic valuation (i.e., that fulfil the three assumptions presented in Section 6.2) are highlighted in red in Figure 8. Typical examples of these are the climate regulating service measured by the carbon sequestered in trees and soils, water, and crop yields.

Figure 8 presents a relatively simple heuristic or 'rule of thumb' to help decision-makers understand the links between ecosystems services (listed along the top row of boxes) and whether these are amenable to economic valuation. The heuristic also, more specifically, helps inform how the diverse values of ecosystem services can and should be measured and incorporated into trade-off analyses to inform adaptation decision-making.

It is clear from Figure 8 that only provisioning services and a subset of regulating services (such as carbon sequestration and water provision, for example) meet all three assumptions of economic valuation. The remaining services can be articulated and evaluated alongside economic values in other metrics, provided the processes allow this. Decision-making processes that allow plural values to be considered and trade-offs assessed in an integrated way, are those that meet the three criteria listed below.

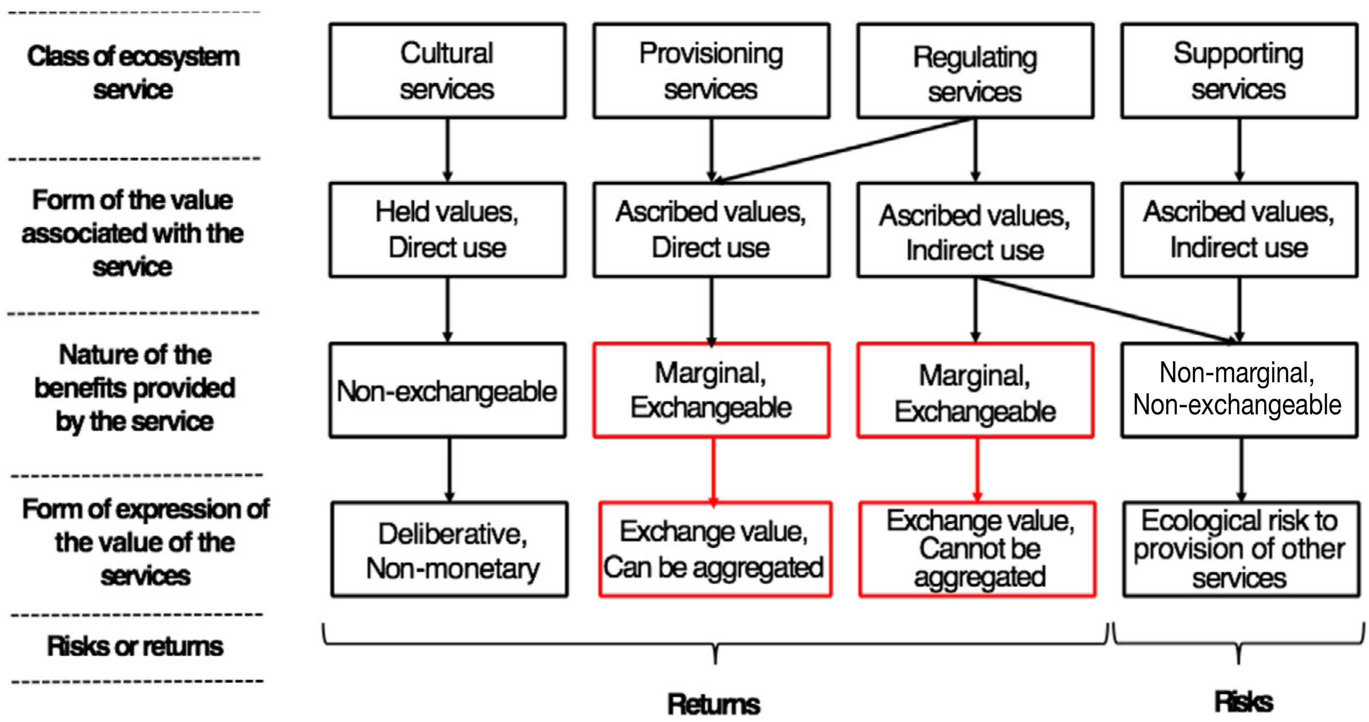

Figure 8: A heuristic framework for expressing ecosystem-service values. The aspects of ecosystem services that are amenable to economic valuation are highlighted in red. Source: Adapted from Abson and Termansen 2010.

6.3 Option values

Option values are particularly important for climate adaptation decisions as they reflect the value of information, timing, and flexibility in decision-making. Hertzler (2007) showed that a form of decision diagram, that can be used in addition to decision trees, can help calculate real-option values and compare the relative costs and benefits of keeping options open or instead, closing those options and creating new ones.

"*An option is often defined as the right, but not the obligation, to take action.*" (Hertzler 2007)

Real-options analysis is the modern analytical method used to model the value of flexibility and the timing of action under conditions of uncertainty (Hertzler 2007). This type of approach seeks to show how decision-makers can manage risk by examining trade-offs between acting sooner than later. Delaying action retains the option to act later and takes into account the value of this flexibility and the value of new information that might help resolve some uncertainty. Option values are particularly important for climate adaptation since they can have consequences that are costly to reverse or irreversible.

The following diagram is the more conventional kind of decision tree (Figure 9). It shows two decisions a farmer will make, (1) to conserve fodder or not and (2) to choose a high rate of cattle stocking or a low rate. In this diagram, squares indicate the branches where these decisions are made.

The branches indicated by circles are events. In this example, the event is whether or not fodder ends up being abundant or deficient. This depends on the decision of the farmer to whether or not to conserve fodder and some environmental chance, due to the uncertainty of the climate.

If the farmer decides to conserve fodder, then the probability of abundant fodder is 1.0 and the probability of deficient fodder is 0.0. If the farmer decides not to conserve fodder, then the probability of abundant fodder is 0.5 and the probability of deficient fodder is 0.5.

Next comes the stocking decisions for each event. After the farmer decides whether to choose a high stocking-rate or a low stocking-rate the branches of the decision tree end with triangles. These triangles indicate the terminal branches. The net return is shown at the end of each branch, calculated as revenues minus costs.

To use this diagram to work out whether the farmer should conserve fodder to get the highest net return, you first work out the optimal stocking rates. For example, if the farmer decides to conserve fodder and fodder becomes abundant, then it is optimal to choose a high stocking-rate with a net return of $250. Likewise, if the farmer decides to conserve fodder and fodder becomes deficient then it would be optimal to choose a low stocking-rate with a net return of $50 (although this is not possible in this example, since the probability of deficient fodder after the farmer has chosen to conserve fodder is 0.0).

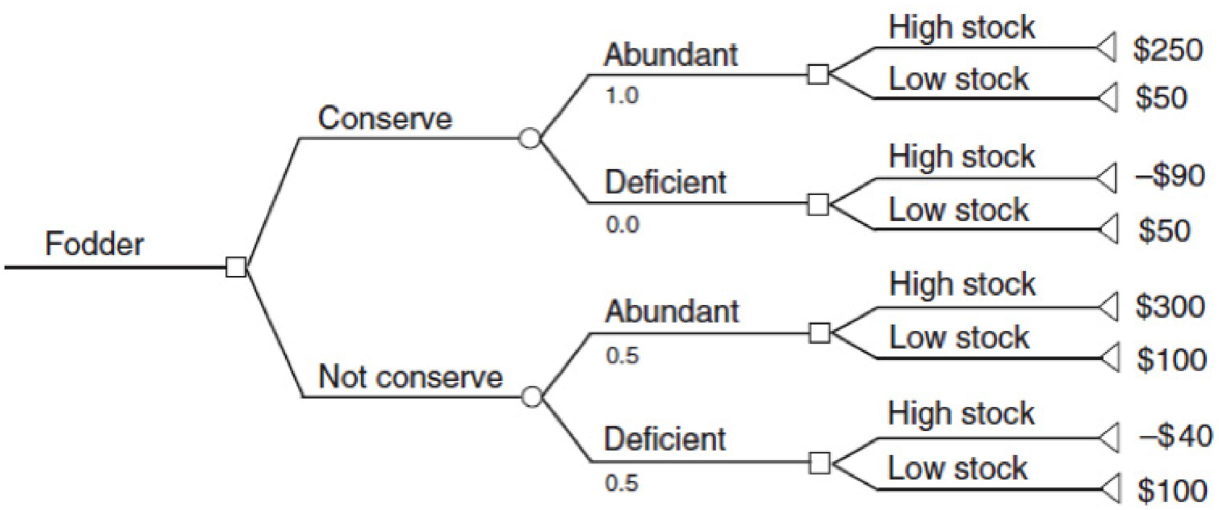

Figure 9: Decision tree for grazing decisions. Source: Reproduced from Hertzler (2007), with permission from CSIRO Publishing.

We then calculate the expected net returns of conserving fodder and of not conserving fodder.

- The expected net returns of conserving fodder = ($250 x 1.0) + ($50 x 0.0) = $250.
- The expected net returns of not conserving fodder = ($300 x 0.5) + ($100 x 0.5) = $200.

It is therefore optimal to conserve fodder in this example.

Hertzler (2007) describes an alternative kind of diagram. Decision trees can get very large and have many branches, which makes it time consuming, as you need to evaluate the whole tree to work out an optimal decision. Instead, Hertzler (2007) provides an approach that exploits Bellman's Principle of Optimality (Smith 1991), so that decision diagrams can be structured as modules and linked. This can be especially useful for evaluating sequences of decisions and for working out if an optimal decision has changed, for example, if new estimates of the probabilities of climate events become available.

Hertzler (2007) shows how the same decision problem above can be analysed using this alternative form of decision diagram. In the following diagram (Figure 10), a grazier's decisions are linked to states of nature. The bottom of the diagram provides descriptions of the stages in the system with each consisting of a state of nature followed by a decision. The "current fodder" stage incorporates the decision whether or not to conserve fodder and the stage "future fodder" incorporates the decision over stocking rate.

Bellman's Principle of Optimality means that decisions can be represented to show how they depend only on the current state of the system. Each stage can be represented as a separate diagram and then linked.

Within each stage, dashed lines are used to link states of nature to decisions. Between stages, solid lines are used to link decisions to the ensuing states of nature. The probabilities that future fodder will be abundant or deficient, depending on the level of current fodder and the decision whether or not to conserve fodder, are shown near these lines.

Three boxes in the diagram are used to record the revenues and costs for each decision and to calculate the net revenue. For example, the net revenue if a high stocking-rate is chosen when fodder is abundant is calculated as $400 - $100 = $300.

In this initial diagram (Figure 10), the ovals are blank, but they will be used later to record the real-option values for states of nature. To calculate these real-options values and work out the optimal decisions, begin with the second stage (i.e., "future fodder").

If future fodder is abundant, it is optimal to choose a high stocking-rate. This has a net return of $300. Write $300 as the real-option value in the oval for abundant future fodder and draw an arrow to the optimal decision "High" (Figure 11).

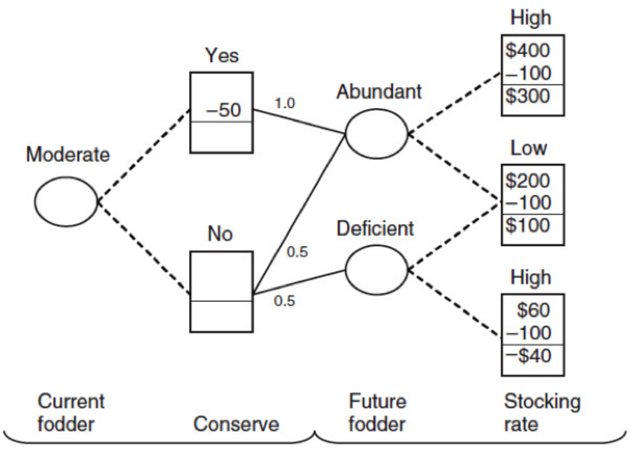

Figure 10: Initial decision diagram for grazing decisions. Source: Reproduced from Hertzler (2007), with permission from CSIRO Publishing.

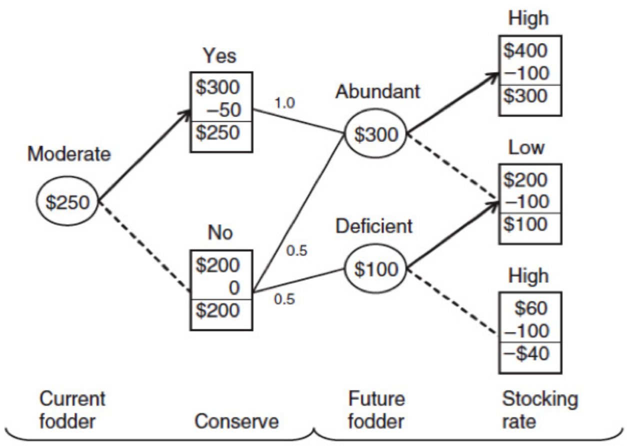

Figure 11: Final decision diagram for grazing decisions. Reproduced from Hertzler (2007), with permission from CSIRO Publishing.

If future fodder is deficient, it is optimal to choose a low stocking rate. This has a net return of $100. Write $100 as the real-option value in the oval for deficient fodder and draw an arrow to the optimal decision "Low" (Figure 11).

Next, look at the first stage. The expected returns from the decision to conserve fodder, "Yes," are $300 x 1 = $300. Write $300 at the top of the "Yes" box and subtract the costs of conserving fodder, $50, to calculate the expected net return of $250.

The expected returns from the decision not to conserve fodder, "No," are calculated as ($300 x 0.5) + ($100 x 0.5) = $200.

The expected net return of $250 from conserving fodder is greater than the $200 expected net return from not conserving fodder. Write $250 as the real-option value of current fodder in the oval at the left-hand side of the diagram.

Notice that this diagram gives the same answer as the decision tree – the optimal decision is to conserve fodder, with an expected return of $250. However, these diagrams show how the answer is calculated and can also be easier to recalculate (Hertzler 2007). These features are particularly useful if a decision problem has many stages or if the probabilities of events change. For example, if a new climate forecast changes the probabilities of abundant and deficient fodder then the second stage in this example would not change and only the first stage would need to be recalculated.

6.4 Rules as pre-requisites for values to be considered in adaptation decision-making

The assessment of costs and benefits of alternatives depends on the institutional mechanisms that allow or disallow different values from being legitimately expressed in the governance of resources and which dictate how resources are allocated. Understanding these institutional mechanisms, therefore, is a precondition to effectively accounting for costs and benefits (Vatn 2009). Gorddard et al. (2012) discuss these dimensions when exploring the difficult trade-offs between public and private values in the context of adapting to sea-level rise and changing inundation risks in coastal Australia.

Institutions (rules) that allow individuals and groups to express their values and enable these values to be accommodated in decision-making are referred to as 'value-articulating institutions' (Vatn 2009). Examples of well-known value-articulating institutions include markets and cost-benefit analysis procedures – effective at articulating economic or monetary values of goods and services – and environmental regulations for helping ensure the intrinsic and functional values of ecosystems are accounted for in decisions.

The suitability of decision processes for accommodating diverse values (social, cultural, economic, and ecological) in integrated assessments of costs and benefits of adaptation depends on the degree to which they (Gómez-Baggethun and Martín-López 2015):

1. build or access the expertise required to undertake integrated valuations of diverse values using inter-disciplinary and specialised (quantitative and qualitative) methodologies;
2. draw upon different types of knowledge relevant for ecosystem valuation, including scientific knowledge, and local, traditional ecological knowledge; and
3. consider values across levels of decision-making (local, regional, national and sometimes global) which requires recognising diverse value-articulating institutions.

Where the decision-making process is found to be wanting in any one of these criteria, it is unlikely it will effectively (credibly or legitimately) examine and account for how values stand in relation to each other (i.e. conflicting or complementary) when assessing the costs and benefits of adaptation interventions. In such situations, a critical first step for this decision-maker will be to diagnose the institutional constraints and then develop, as part of their adaptation pathway, a strategy for overcoming these constraints through participatory engagement with communities and higher-levels of decision-making (See Section on Adaptation Pathways). The importance of this cannot be understated because assessing adaptation options is often not about calculating a number then making a Yes/No or Go/don't Go decision. Upfront clarification of fundamentals such as whether the problem definition has been adequately reflected upon and diagnosed, and whether decision-makers can legally, legitimately or credibly propose and act on adaptation options, is critical before scoping and undertaking a benefit/cost appraisal.

6.5 Situations under climate change that challenge existing approaches to valuation

Existing approaches to valuation and decision-making will be particularly challenged in situations where the impacts and consequences of climate change will be non-marginal, unprecedented or fundamental in nature (i.e. where ecosystem processes and structures fundamentally transform). And since these changes are becoming increasingly likely, and on a large scale with delays in scale and timing of global mitigation agreements, it is critical to consider their implications for valuation to inform decision-making.

Examples that are particularly pertinent to the coast, and where some precedent and early indications exist, are those where particular ecosystems change species, structure or processes, (i.e. their identity) as the environmental conditions make it untenable for the prevailing system to maintain its identity as defined by its composite species, structure and processes. Two examples can be usefully distinguished based on the rate of change and include:

1. rapid, non-marginal, and (effectively) irreversible changes such as coral bleaching or loss of beaches and dunes as they are eroded or permanently inundated by rising sea levels and extreme storm events
2. gradual shift in the identity (species or processes) of an ecosystem in a location as it draws upon intrinsic ecological mechanisms to adapt and transform itself to survive under a changing environment (Abson and Termansen 2010).

In such situations it is more likely that individuals and communities will not be aware of all the values being lost as systems transform. Nor will they have any understanding or experience upon which to inform their values and preferences for the transformed system. These contexts make it difficult, if not impossible, to perform long-term economic analyses based on assumptions that values are known and remain stable over time under large-scale change (Lavorel et al. 2015). Also, since values and views change over time, present-day actions or inactions are likely to be viewed and judged quite differently by future generations (Heyward 2008). Yet, most existing policies are made under the assumption that existing preferences and prioritized values (i.e., economic values) will remain equally relevant across generations and can simply be adjusted using a discount rate (O'Brien and Wolf 2010). What seems to be clear though, based on understandings of social development and human psychology (Toman 2006) is that over time, individuals and groups "are likely to... take a broader perspective" than the largely economic orientation of today, that includes a more holistic understanding of nature–society relationships. Additionally, as temperatures increase and other impacts are directly experienced by individuals and groups in society, climate change may become a catalyst for challenging belief systems and worldviews, and ultimately fundamentally shift prioritised values (O'Brien and Wolf 2010).

In dealing with uncertainties and complexities there is no substitute for participatory processes of engagement, deliberation and negotiation around the nature of the problem and the canvassing of diverse, novel values is essential.

7 Examples of assessing adaptation strategies for avoided damage

Although, as Dobes (2012) warned, 'damage costs avoided' are a poor proxy for people's preferences for climate adaptation, as would be reflected in their willingness-to-pay, a number of studies that estimate the damages avoided by alternative adaptation strategies can be used to demonstrate the importance of early action, financial constraints, and the distribution of costs and benefits in adaptation decision-making.

7.1 Adapting coastal residential buildings to storm surges and rising sea levels

Wang et al. (2015) compared alternative national policy stances for adapting coastal residential buildings to storm surges and rising sea levels for the increase in sea levels associated with alternative scenarios.These are shown below.

Adaptation actions	Scenarios
• protection via the construction of seawalls • accommodation of climate change impacts by raising floor heights, and • avoiding impacts by limiting new developments in hazardous areas.	• three alternative emissions scenarios (A1FI, A1B and B1) (IPCC 2000) • three urban development scenarios (business-as-usual, urban consolidation, and inland regional development) • static, reactive, anticipatory and baseline policy stances

Combining an anticipatory policy stance and adaptation actions to protect against storm-tide surges reduced expected damages to residential housing to around $200 million with a net benefit of around $4 billion up to 2100 (Net Present Value, $2006, 2.6% discount rate) in comparison with current building standards based on historical climate information (Wang et al. 2015).

Seawalls were used to illustrate coastal protection in order to simplify the modelling, whereas in practice, alternatives such as beach nourishment, groynes, artificial reefs, or replanting mangroves could be cheaper and have higher net benefits by avoiding the loss of amenity and ecological damage associated with seawalls (Wang et al. 2015).

7.2 Distributional issues of adaptation options in coastal residences

Fletcher et al. (2013) analysed the distribution of costs and benefits using case studies selected from the residential sector in six Australian coastal communities within Moreton Bay, the Sunshine Coast, and Cairns, to examine alternative adaptation strategies for responding to the risk of coastal inundation. This study used a financial cost-benefit analysis to consider the affordability of adaptation and the consequences for property values that did not include sources of non-market values. The results are indicative, but should not be used to directly inform decision-making without considering other kinds of costs and benefits in the analysis.

What this analysis does show, however, is that adaptation actions that can have benefits that exceed costs for a whole community may not be affordable based on the budget available for adaptation. This also means that the distribution of costs and benefits across a community is very important for assessing the equitability of alternative adaptation strategies. For instance, in some cases a very small number of households might receive a large benefit from a community-level adaptation while most households gain little or no benefit. For example, Fletcher et al. (2013) found that for many case studies most people would not receive a net benefit by contributing to a community-level adaptation such as a seawall.

7.3 Adaptation of coastal urban communities to extreme winds

Stewart and Wang (2011) investigated adaptation strategies for mitigating the impact of extreme wind events such as tropical cyclones and severe storms on four coastal and urban communities in Queensland, specifically, Cairns, Townsville, Rockhampton and Brisbane. With current design standards based on the assumption of a static climate, the higher wind speeds brought by climate change will lead to increased damage to homes in these cities. This vulnerability could be reduced by updating building standards to cope with higher wind speeds (i.e. Australian Standards AS4055-2006 and AS1170.2-2011) (Adaptation Strategy 1), retrofitting pre-1980 buildings to current standards (Adaptation Strategy 2), or repairing pre-1980 wind-damaged houses to current standards (Adaptation Strategy 3). Adaptation Strategy 1 involves changing the Australian Standard, "Wind Loads for Houses," so that new constructions and alterations are designed to resist 50% higher wind pressures.

This study demonstrated that even without any climate change, increasing building standards can still be cost-effective. There is a 97.6% likelihood that Adaptation Strategy 1 would result in a mean net present value of $202.7 for Brisbane foreshore locations. Stewart and Wang (2011) noted that this strategy makes sense as a no-regrets policy. Further, there is evidence of benefits from early adaptation action, since net benefits in the form of damages avoided accumulate over time. Delaying action until 2020 or 2030 would have a lower net benefit compared to immediate implementation.

8 Adaptation pathways

Climate adaptation efforts are faced with the challenges of large unprecedented changes to ecosystems, to socio-economic activities, and to individual and social values. Such changes mean the decision contexts of most decision-makers will be characterised with many uncertainties that cannot be resolved with more research, interested and affected decision-makers across multiple jurisdictions, and ambiguous goals.

Managing the impacts of rising sea levels and increasing frequencies and intensities of storm events on coastal communities provides an example of these changes and adaptation challenges. Real-estate markets, insurance markets, and local government planning and decision-making processes all rely on rules for development and conservation planning along the coast; however, these rules have not evolved to account for the extreme, cross-scale and sometimes highly contested risks associated with sea level rise. These risks are also often unprecedented (at least locally) in many areas and communities are not aware of what is at stake. This means that adaptation decisions are either not recognised as necessary, purposefully delayed, focused on managing short-term considerations, or continue to be influenced by the vested interests of property owners or developers, with the likely result that coastal communities will lock themselves into increasingly costly futures involving continually building defenses, repairing damaged infrastructure, and losing beaches, dunes and estuaries. Planning for major changes such as sea level rise and increasingly severe storms and extreme flooding and inundation events, requires coordinated responses of many distributed decision-makers, and that these responses not only ensure short-term essential services, but initiate longer-term strategies for overcoming the systemic causes of vulnerability.

Existing decision-making processes and tools are limited in their ability to help stakeholders understand such problems and to deliberate over possible responses to such global changes and impacts. This is particularly the case where choices involve some stakeholders winning and some losing (over space and time), or where private interests (e.g. beachfront properties) conflict with broader community and environmental values (e.g. continued existence of beaches and dunes).

8.1 Adaptation pathways – a powerful metaphor and structured decision-making approach

Adaptation pathways is a relatively new conceptual and analytical approach for enabling adaptation planning and decision-making in contexts of deep uncertainty and inter-temporal complexity[18] 'Adaptation pathways' refers to the flexible plans of an organisation or region, comprising sequences of alternative prioritised courses of action, and whose implementation is informed by increasing understanding of the interactions between environmental changes and human wellbeing under climate change, in response to interventions. Numerous definitions of adaptation pathways exist in the literature and are summarised in Box 2.

The implementation of adaptation pathways requires the identification of 'decision triggers' that 'kick-in' processes of re-evaluation and updating of the selected and alternative adaptation pathways. Importantly, decision triggers need to be informed by understanding of the variable(s) driving/controlling the identity of the system (e.g., sea level, fire regime, predominant land-use practices, etc.), critical levels of these variables beyond which the identity of the system fundamentally changes (i.e., thresholds), and underpinned by effective monitoring, evaluation and learning processes.

[18] Complexity is a way of thinking about complex systems that involve large numbers of interacting elements, where interactions are nonlinear and dynamic and lead to emergent unpredictable behaviours (Cilliers 1998; McDaniel 2007; Snowden and Boone 2007).

Box 2: Definitions of adaptation pathways

The Route Map (Pathways) approach
(Reeder and Ranger 2011)

The route-map approach (or decision pathways approach) is a method of designing robustness to climate change uncertainties into the adaptation strategy itself. Rather than taking an irreversible decision now about the one or two 'best' adaptation options to cope with climate change (which can lead to maladaptation if the climate scenarios planned for do not emerge), it encourages a decision maker to postulate "what if" outcomes and take a more flexible approach, where decisions are made over time to continuously adapt while maintaining as much flexibility as is desirable about future options. This approach aims to ensure that whatever short- to medium-term plan is adopted, it is set in a framework that will not be maladaptive if climate change progresses at a rate that is different from what is predicted today.

Dynamic adaptive policy pathways
(Haasnoot et al. 2013)

Adaptation Pathways provides an analytical approach for exploring and sequencing a set of possible actions based on alternative external developments over time. Adaptation Pathways provide insight into the sequencing of actions over time, potential lock-ins, and path dependencies. Central to adaptation pathways are adaptation tipping points; the conditions under which an action no longer meets the clearly specified objectives. The timing of the adaptation point for a given action, its sell-by date, is scenario dependent. After reaching a tipping point, additional actions are needed. As a result, a pathway emerges. The Adaptation Pathways approach presents a sequence of possible actions after a tipping point in the form of adaptation trees (e.g. like a decision tree or a roadmap). Any given route through the tree is an adaptation pathway.

Adaptation as part of pathways of change and response (Wise et al. 2014)

Wise et al., (2014) builds upon these approaches to adaptation pathways and emphasises several core principles. First, climate change impacts and responses cannot be considered in isolation, but are components of dynamic, multi-scale social-ecological systems. Second, adaptation involves multiple stakeholders with competing values, goals and knowledge which must be recognised and negotiated. Third, responses to change must be coordinated across spatial scales, jurisdictional levels and sectors. Fourth, planning processes should design and implement incremental adaptation strategies to address proximate causes or symptoms of vulnerability, plus transformative strategies to tackle systemic causes, which in developing countries are often the institutional and political roots of disadvantage. And fifth, to avoid mal-adaptation, strategies should be 'no regrets' (i.e. yielding benefits under any future conditions of change) and decisions to implement them should be sequenced over time informed by understanding of interactions between changes and responses.

The adaptation pathways approach, as a metaphor and as a conceptual and analytical framework, helps users consider and implement in a more structured way, the three critical iterative and interacting aspects of adaptation planning:

1. Diagnosis of the adaptation challenges caused by interacting economic, population, climate and ecosystem changes;
2. Development of context-sensitive adaptation pathways involving the identification, prioritisation and sequencing of adaptation interventions under different scenarios of change; and
3. Adaptive management and governance of pathways (i.e. of aspects 1 and 2) based on monitoring, evaluation and learning.

8.2 Generic activities to developing adaptation pathways

Numerous approaches to the development and implementation of adaptation pathways have been developed and used in recent years. Interested readers can access each of these approaches at the links provided in Table 3.

Seven generic activities in the development of adaptation pathways are presented below, which were found to be reasonably consistently used in all of the adaptation pathways approaches listed in Table 2. This list should be viewed as a guide and heuristic and should be adapted to fit your existing needs and processes.

Table 3: Some of the recently proposed approaches to adaptation pathways (links accessed 20 April 2016).

Title / name of approach and proponent	Reference source
Route maps (Thames barrier) – Reeder and Ranger (2010) and the UK Environment Agency (2012)	https://www.gov.uk/government/publications/thames-estuary-2100-te2100
Dynamic Adaptive Policy Pathways - Haasnoot et al. (2013)	https://www.deltares.nl/en/adaptive-pathways/
Enabling Adaptation Pathways – Wise et al., (2014)	https://research.csiro.au/eap/ http://www.sciencedirect.com/science/article/pii/S095937801300232X
The Resilience, Adaptation Pathways and Transformation Assessment (RAPTA) Framework – O'Connell et al. (2015)	http://www.stapgef.org/the-resilience-adaptation-and-transformation-assessment-framework/
Adaptation pathways: A playbook for robust options in natural resource management – Bosomworth et al. (2015)	https://www.terranova.org.au/repository/southern-slopes-nrm-collection/adaptation-pathways-a-playbook-for-developing-options-for-climate-change-adaptation-in-natural-resource-management
Applied adaptation pathways on the Eyre Peninsula, South Australia – Siebentritt et al. (2014)	http://nrmrain.org.au/2015/07/applied-adaptation-pathways-on-the-eyre-peninsula-south-australia%e2%80%a8/

Activity 1: Determine the nature (rate and magnitude) of the drivers of change and the potential consequences of these for livelihoods (i.e., for what is important or valued by people) or for whatever the focal domain or context is, be it protected area conservation or water management.

Activity 2: Characterise the desirable goal/vision/ end point, given the understanding of the changes and their consequences; and particularly assess the achievability of current goals in light of the understanding of projected changes and impacts.

Activity 3: Identify the focal decision-makers or decision-making processes and the particular decisions that they: currently make, need to stop in the future, may need to make in the future, or definitely need to make in the future, in order adapt to changes to realise a goal (illustrated in Figure 12).

Activity 4: Explore the timing of these decisions or actions with respect to:

- The lead and consequence times of decisions (i.e. considering the decision planning, implementation and impact times)
- The dependencies on other decisions/actions (i.e. the role of each action in paving the pathway for other actions) and the effects on other adaptive options
- The dynamics of climate change, and ecological and human responses (i.e. are the decisions/ actions robust to diverse futures? Can they be easily stopped or reversed if conditions change? Are they likely to be effective at averting the crossing of a threshold?)

Note: this information will be used to inform decision triggers that instigate a process of review, re-evaluation and re-development of the adaptation pathways.

Activity 5: Further prioritise decisions/actions/ options based on:

- The relative magnitudes of their expected net benefits (feasibility) under different scenarios of change – refer to section on estimating costs and benefits (including ideas of option values, opportunity costs, and the value of information)
- Their relative ability to fulfil immediate imperatives (basic needs, regulatory requirements) while maintaining or enhancing options in the future
- Their co-benefits (GHG mitigation, equity (gender, income, etc.), environmental and contribution to disaster risk reduction).

Activity 6: Identify the requirements for making each decision and implementing actions (i.e., assess whether their context (vrk) is enabling or constraining of these adaptation options)

- Is there sufficient knowledge / understanding about the nature of change and efficacy and effectiveness of interventions and what is the salience, credibility and legitimacy of this knowledge
- What is the sphere of influence and control (i.e. are the decision-makers mandated to make these decisions and do they have the agency to do so)?
- Do the decision-makers have the support of their electorate or civil society more broadly (i.e. is what they are proposing or have to do considered acceptable and legitimate)?

Activity 7: In situations where it is found in Step 2 that existing goals are incompatible (impossible) in light of the projected nature of the changes, then it is unlikely the decision context of rules and values will enable this new goal to be realised, therefore many of the adaptation decisions identified in Step3 will be revealed by answering the questions under Step 6.

Each of the seven activities above is relevant to all adaptation decision-making and planning contexts. The approaches to and outcomes of each activity, however, can be quite different depending on the context and capacity of decision-makers, and will influence how adaptation pathways are developed and implemented. This is elaborated upon in the next section.

8.3 Categorising adaptation pathways approaches to decision context

The existing approaches to adaptation pathways can be meaningfully categorised along a spectrum of adaptation problems or decision challenges, described by combinations of different levels of three variables:

- The degree or level of ambiguity in goals
- The level of uncertainty in knowledge
- The distribution of power (i.e. the diversity and number of interested and affected actors across jurisdictions and levels of decision-making with varying levels of power and influence)

The decision or problem space as defined by the combination of these variables is depicted in Figure 12; and some of the adaptation pathways approaches have been loosely mapped into this space, based on rough assessments of the decision contexts for which each of these particular examples was developed.

The **Thames barrage 'route maps'** approach (Reeder and Ranger 2011; UK Environment Agency 2012), for example, was developed to inform cost-effective investment strategies to upgrade the Thames barrage (and its infrastructure) in the face of uncertain rates and magnitudes of sea level rise and the threat of inundation of high value assets. In this example, there is a clear decision-maker with the mandate and agency to choose and act on options. There is also a clearly defined, unambiguous goal, namely to prevent London from being inundated. And finally, the adaptation challenge or problem is relatively simply characterised by a single controlling variable, the level of the Thames River; although there is substantial uncertainty regarding the interacting affecting, such as tides, storms and sea level rise. High-reliability decision contexts such as this, where there is a clear decision-maker with an unambiguous goal, are more amenable to the development of adaptation pathways as route maps comprising clearly delineated discrete options and pathways over time for dealing with the high levels of uncertainty to changes in the threat.

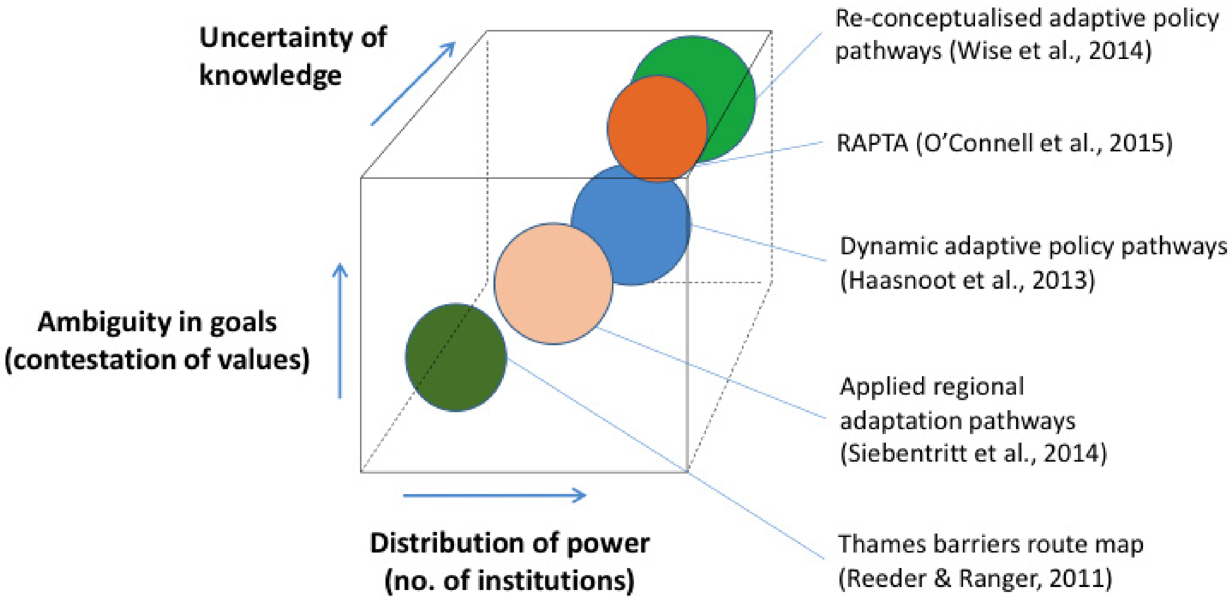

Figure 12: Illustration of the loose classification of the various current approaches to adaptation pathways listed in Table 2, based on the characteristics of the context (combinations of levels of ambiguity in goals, distribution of power and uncertainty in knowledge) for which each approach has been specifically designed to address. Source: Developed by authors.

The **'dynamic adaptive policy pathways'** approach (Haasnoot et al. 2013) was developed to inform water management in river catchments experiencing competing and growing water demands and increasingly variable and declining, yet highly uncertain, projections of supply. In this situation the goals are reasonably unambiguous and agreed. The current knowledge and predictability of future possible states of the system in terms of water supplies and demands are influenced by uncertain changes in climate and its impacts on rainfall, and by uncertainties in societal policy and developmental responses. Additionally, there are many affected stakeholders representing diverse interests, jurisdictions and ideological perspectives, making agreed interventions and planning extremely difficult. This analytical approach and the pathways diagrams are specifically developed to be implemented within participatory processes involving interested and affected stakeholders, to promote deliberation and negotiation around preferred pathways.

The **'enabling adaptation pathways for societal change'** approach (Wise et al. 2014) was developed to inform and build the capacity of decision-makers responsible for making investment and management decisions with long lifespans or long-term consequences, and where climate and other global changes will are likely to interact in non-trivial and uncertain ways. The approach comprises a suite of concepts, tools and processes to guide and build the capacity of interested and affected stakeholders to:

- diagnose and frame adaptation problems (particularly recognizing that changes in natural environments will be transformational and require transformational responses focused on addressing systemic causes of vulnerability);
- identify barriers to the adaptation options they can legitimately consider and implement;
- develop pathways for overcoming systemic barriers to adaptation and for guiding transformational responses to projected unprecedented large-scale change; and
- develop and adopt adaptive learning procedures via targeted interventions and regular reflections on the institutional, cultural, and personal dimensions constraining or enabling transformational adaptation.

The **'applied regional adaptation pathways approach'** approach (Siebentritt et al. 2014) was developed as an initial phase of a longer-term pathways approach to informing regional scale, cross-sectoral adaptation planning to deal with diverse drivers of change and comprising widely distributed decision-makers. The approach combined current conceptual thinking on adaptation pathways, best available science on the impacts of climate change on key sectors in the region with a engagement process delivered through interviews and workshops with key regional leaders. Key regional influencers were identified and their input informed pre-workshop discussion papers. This process ensured that participants knew they had been listened to and that at each workshop they came ready to actively participate. Involvement and knowledge from industry participants also helped improve the design of the workshop process. The engagement process proved to be exciting, producing real cross-sectoral involvement and interaction. The result has been a series of adaptation pathways for key sectors on the Eyre Peninsula that express the range and timing of adaptation options and assist in identifying region-wide and sector specific adaptation priorities, now and into the future.

In summary, although all of these adaptation pathways approaches draw upon the same set of key principles or criteria, they each develop and use their own, sometimes overlapping, sets of guidelines, tools and processes for informing the development and implementation of adaptation strategies and plans. These adaptation pathways approaches are readily accessible online, in publications, or by contacting their developers directly. The details of the sources of this information have been provided above.

8.4 An illustrative example: Adaptation pathways in the local coastal context

Historical institutional arrangements and management decisions enable and constrain coastal adaptation (Moser et al. 2012). New forms of community engagement and governing institutions are needed to help overcome the challenges of coastal climate adaptation (O'Riordan et al. 2008). Coastal regions are often faced by complex, overlapping and confusing governance arrangements that make agreement over managing coastal change (O'Riordan et al. 2008) more difficult. The capacity to make adaptation decisions is impeded at a local level by divisions in public opinion about the need for adaptation and how it should be implemented (Barnett et al. 2013). When there is public indifference and external interventions have limited influence, local governments may fail to anticipate risks and act accordingly even though they are at risk of great losses (Burby 2006).

Coastal systems are dynamic and changeable and adaptation decisions must respond to unfolding circumstances under conditions of great uncertainty. Barnett et al. (2013) suggested that adaptation pathways can help build consensus among diverse constituencies about the need to adapt to coastal climate change impacts such as sea-level rise. Decisions in this context need to consider long time horizons, long lead times, time lags, and tipping points (Moser et al. 2012). With this complexity, adaptation pathways might help frame adaptation as a manageable process (Barnett et al. 2013).

An adaptation pathway becomes a sequence of linked strategies that are triggered by changes in conditions such that early decisions can have low regrets, low risks, and preserve options for the future. For example, the identification of no-regrets options can demonstrate that investing in climate adaptation can have benefits even in the absence of future climate change (Moser et al. 2012). Berke and Lyles (2013) suggest that developing scenarios that consider combinations of no-regrets, low-regrets, and contingent actions as part of a staged approach should make adaptation planning evocative, tangible and relevant for all parties.

Processes for developing adaptation pathways have begun for a number of large coastal cities (Jeuken et al. 2015). However, the lessons learned in this context might not be as applicable to regional coastal towns (Barnett et al. 2013). Local decision-makers do not have the assets and capacities of large cities, nor do they have the same technical and financial capacity. Their problems are less likely to provide a clear mandate for action, and decisions at local scales rely more heavily on consensus within local constituencies. In this context, Berke and Lyles (2013) argue that local governments need planning approaches that formulate multiple futures and flexible strategies that prepare for change and build a public constituency that supports decision-making under uncertainty. They suggest that planning needs to (1) develop a knowledge-base through the collaborative formation of scenarios that anticipates multiple futures and associated impacts, (2) formulate flexible adaptation policies, and (3) implement policies and monitoring outcomes (p. 193).

From this perspective, early stages of an adaptation pathway might aim to build adaptive capacity by seeking to better understand the problem, educating and building awareness among stakeholders, increasing collaborative ties with scientists and government, improving data sharing and communication, or developing funding mechanisms (Moser et al. 2012).

Berke and Lyles (2013) list a number of common shortcomings that have been identified by studies of hazard mitigation plans. These include goals that are too narrowly defined; processes that identify hazards and risks, but do not account for a range of possible future changes; policies that focus on narrowly conceived structural projects; an unclear assignment of organizational responsibility, timelines and funding; and monitoring programs that fail to specify indicators or sources of data for tracking progress.

Adaptation pathways approaches aim to incorporate the elements of adaptive risk management of climate adaptation. These elements include (1) processes for risk identification, assessment, and evaluation, (2) iterative decision-making and deliberative learning, (3) flexibility and robustness, (4) policies and institutions for adaptive management over long time-frames, (5) a portfolio of approaches, and (6) effective processes for communication and stakeholder inclusion (National Research Council 2010).

9 Tips and traps

1. A major potential mistake in decision-making is giving more weight to the types of costs and benefits that are more easily quantified. Under conditions of uncertainty, we have good reasons to think that the costs and benefits that are harder to quantify in monetary terms, such as option values and non-market values, are likely to be relatively higher than those that are relatively easier to quantify, such as house prices. An excellent example of this is the Stern Report (2006) in which the estimated non-market benefits were some orders of magnitude greater than the estimated market-derived values.

2. Conversely, there is a risk that under climate change, many of the assumptions needed for various methods of non-market valuation, to give reasonable estimates of non-market values in monetary terms, will not be met. Russell (2001) warned that non-market valuation estimates of values in monetary terms assume we are choosing from fairly stable alternatives that all support something close to current living standards and are therefore unlikely to be very good for estimating damages from catastrophic changes or regime shifts.

3. Portfolio management approaches can be used to assess the costs and benefits of diversification (e.g. Aerts et al. 2008) and should be included as an essential component of cost-benefit analysis (Boardman et al. 2010).

4. It is important to note that economists often use the terms 'cost-benefit analysis' (or 'benefit-cost analysis') to refer to specific procedures for comparing costs and benefits in monetary terms, but that there are also other procedures available. For example, if all you care about is the number of apples you have, then the metric 'number of apples' is sufficient for comparing how well alternative courses of action satisfy your preferences.

5. Social cost-benefit analysis seeks to aggregate people's individual preferences to obtain a value for society. This is easier if costs and benefits can be evaluated in monetary terms and expressed as net present values in order to facilitate comparisons. Sometimes, however, an analysis is conducted of only those costs and benefits that can be estimated readily from market data or only the costs and benefits experienced by a single institution are included in an analysis. Economists sometimes use the term 'cost-benefit analysis' as shorthand for 'social cost-benefit analysis'. The word 'social' here means that this is an attempt at an analysis of all costs and benefits, regardless of who experiences them, so comparisons using only market data or comparisons that don't attempt to analyse all costs and benefits, regardless of who experiences them, are not complete social cost-benefit analyses.

6. The idea of cost-benefit analysis is to take into account all costs and benefits for the economy and society. Although, in theory, market prices can provide an accurate measure of the value of scarce resources if a number of assumptions are met, in practice, a combination of market data and non-market valuation is used to provide the necessary information about costs and benefits, including use and non-use values. Whilst methods for economic valuation seek to consider all types of value, economic valuation does not estimate a total value for costs and benefits, but instead estimates relative to a business-as-usual or baseline scenario. In other words, valuation estimates whether welfare is improved by an alternative course of action. This helps us assess the trade-offs and hopefully identify an alternative with a higher net benefit.

7. Make your assumptions explicit, and explicitly test your assumptions in a sensitivity analysis. Remember, the outcome of a cost benefit analysis is not the final solution. The outputs of economic analyses should put into a political and deliberative process along with many other inputs, including qualitative measures of impact.

8. Avoid confounding environmental, ethical and economic issues in a single analysis. For example, don't use different discount rates for different variables. Where there are trade-offs between economic, ethical and social dimensions, quantify these explicitly and ensure these are considered in participatory deliberative processes.

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