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A review of integrated assessment frameworks for environmental management

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Introduction

Sustainable management involves the consideration of economic, environmental, and socio-cultural factors (Ciccullo et al, 2018). In this review, the environment is considered in a broad sense, and includes the many benefits that humans derive from ecosystems, often termed 'ecosystem services' (Bouma and van Beukering, 2015). Characterisation of how ecosystem services are affected by past, current, and future human activity is gaining traction as a primary method of guiding policy development (Costanza et al., 1997; Kubiszewski et al, 2017). Nevertheless, the integrated assessment of the cultural, economic, environmental, and social impacts of management action is complex. This stems from uncertain scientific evidence and strong value conflicts (Pielke, 2007). In particular, the lack of information relating to the cause-and-effect relationships between various elements of the problem. Additionally, it is challenging to quantify or describe values, and determine the right balance between such elements when determining the relative suitability of a certain outcome.

The breadth of ecosystem services affected by human activity is not reflected in standard methods of economic assessment. Neo-classical economic evaluation focuses on the assessment of marginal effects – the difference between the business-as-usual (that is 'without policy' states) and an alternative future (that is 'with policy' state) (Boardman et al, 2010). These effects are generally cast in monetary terms using what some authors term a 'monistic' frame (Summers et al, 2012), as opposed to a 'pluralistic' approach that exploits a diverse range of criteria (Norton and Noonan, 2007). Benefit-cost analysis (BCA) will often be used where the scale of benefits associated with environmental improvement are estimated using non-market valuation (Doole et al, 2016a). In comparison, cost-effectiveness analysis (CEA) is typically applied where the cost of reaching certain environmental targets is assessed, with no explicit consideration of the scale of benefits associated with them (Kampas and White, 2004).

Neo-classical methods of assessment play a central role in environmental policy making. This is particularly relevant in New Zealand where key concepts of efficiency, benefits, and costs are clearly expressed in the Resource Management Act 1991. However, extensive application has identified several limitations with these approaches:

- Not all changes in ecosystem services can be valued in monetary terms. For example, some people contend that it is philosophically wrong to place a monetary value on cultural and ecological values (Norton and Noonan, 2007).
- Even if it were ethical to monetise all values associated with changes in the environment, the breadth of ecosystem services makes it difficult to monetise these values (Porter et al, 2009).
- Monistic approaches appear to provide for sharper comparison, but focus mainly on items that are easily valued and do not clearly display the uncertainty and value conflicts that underlie many environmental problems (Batie, 2008)
- There is a distinct lack of scientific information on many of the environmental services impacted by management (Pielke, 2007).
- Assessing policies with respect to their impact on a limited set of ecosystem services provides a biased appraisal (Balvanera et al, 2001).
- Non-market valuation studies require too much resource in terms of expertise, money, and time (Rogers et al, 2015).

- Estimation of marginal impacts does not consider the total level of degradation that occurs under current management (Johnstone et al, 2008). This means there is minimal or no information available relating to the current cost of degradation.
- Marginal analysis favoured in economic theory does not consider the existence of biophysical thresholds. This limits the approach given that small changes in management leading to a threshold being breached can result in significant changes in ecosystem condition (Farley, 2008).

These limitations with conventional forms of economic assessment highlight the value of other frameworks.

The objective of this document is to provide a focused review of alternative, and potentially complementary, frameworks for the integrated assessment of the economic, environmental, and socio-cultural effects of environmental management. Here we look at the core characteristics of these methods. The degree to which each framework differs in their consideration of the design criteria will inform the relative strengths and limitations of each approach.

Design criteria for assessment frameworks

The suitability of alternative methods of assessment depends on many criteria. These criteria reflect, both individually and together, the complexity of socio-environmental systems and the context of evaluation. This section identifies a series of principal design challenges for performing evaluation. These are used in the following section as a way of comparing alternative approaches to assessment. The principal design challenges are:

Typical level of resolution

The breadth of application can change, given diversity in the resolution of different ecosystem-services assessments (Grunewald and Bastian, 2015). Examples of ecosystem-service valuation in the literature range from the paddock (Maseyk et al, 2018) to global levels (Costanza et al, 1997).

A flexible framework should easily scale according to extent of the proposed assessment. The comparison between frameworks presented below studies the typical level of resolution, which is usually determined by the accessibility of the framework in participatory work and its capacity to scale well when sufficient resources are available.

Suitability for participation

The use of information by decision-makers will be encouraged where the process of development and assessment is participatory in nature (Vennix, 1996). This criterion reflects how suitable the framework is for participatory development and application; chiefly, by non-experts with diverse experience and perspectives.

Type of data

The units used to represent both model inputs and outputs can vary from one to many. This aspect of a framework influences clarity, breadth, and the resources required for translating diverse data to a common metric.

Typically, ecosystem-service assessment frameworks need to deal with both quantitative and qualitative data, given the diversity in the types of information available for the various elements of a system.

Risk and uncertainty

Risk represents the probability distribution of outcomes associated with a decision, while uncertainty denotes outcomes for which the probability distribution is unknown (Doole and Kingwell, 2010). Both are common characteristics in decision problems associated with integrated catchment management.

The capacity for an assessment process to deal with variable data helps to provide insight into how this impacts outcomes (Philpott et al, 2013). Nonetheless, assessment frameworks differ in their ability to deal with these features of a problem.

Clarity of framework

An assessment framework needs to be intelligible and understood by others, if it is to be credible and trusted (van den Belt, 2004). This involves helping to develop a shared understanding of the cause-and-effect relationships that exist within a system (Vennix, 1996; Connolly, 2017).

Clarity of output

Making decisions around environmental management requires the processing of outcomes by multiple parties, especially in a world where collaborative governance is becoming the norm. This is aided by a framework that provides information in a clear and concise manner to users from diverse backgrounds and level of scientific training (Luna-Reyes et al, 2006).

Together with these criteria, sample references provide further information to the interested reader.

Frameworks

Below a range of frameworks are compared with respect to the design criteria listed on pages 6-7. The type of analysis undertaken in each method varies in relation to the design criteria. The methods considered are:

Benefit-cost analysis (BCA): This method focuses on evaluating the benefits and costs of a 'with policy' scenario over time, relative to a 'without policy' scenario. It is typified by the quantification of these benefits and costs in monetary terms. In an environmental context, the benefits of policy actions are typically estimated through non-market valuation.

Augmented BCA: This framework involves augmenting standard BCA with a qualitative assessment of how actions will impact various outcomes that are difficult and/or expensive to monetise. This approach is more holistic than standard BCA, but means that criteria – such as the net present value and benefit-cost ratio rules – typically utilised to determine the value of alternative options are less straightforward to apply.

Probabilistic BCA: This method involves the classification of some or all the inputs to a BCA as random variables defined by probability distributions. Defining some or all the inputs as random variables yields the output variables of the assessment as random variables, too.

Causal-loop model: This method examines the cause-and-effect between different elements within a system. Relationships are designated as positive, negative, or indeterminate, but are not quantified. Typical formalisms also involve a classification of whether or not the links between different elements are delayed. A feature of this type of model is its ability to represent feedback loops between system elements.

Fuzzy logic mapping: This method involves the extension of a causal-loop model to include information regarding the certainty and strength of the causal relationship that exists between elements in a system. This allows the impact of a relative change in certain variables on other factors to be ascertained.

Policy graph: This is a qualitative tool that is used to describe how elements of a system are related across time in the presence of risk and uncertainty. It arises from the field of stochastic programming where it is used as a device to help communicate complex models and solution methods (Puterman, 1994).

Expert assessment: This approach involves a structured process of bringing together experts to assess how a change in management would affect aspects of a complex system. This approach encompasses a broad range of methods that vary in relation to the composition of the expert group and how their inputs are integrated during the assessment process. Typically, it is focused on a wide range of measures for which there is high uncertainty for cause-and-effect. An implication of this is that it is difficult to be precise with respect to potential effects, leading to broad statements around how a change in management will affect various elements of the systems. Examples are narrative descriptions, 'traffic-light' systems, or 'smiley-face' assessments.

Delphi techniques: These are structured assessment procedures that involve multiple rounds of anonymised assessments carried out by experts. An anonymised, justified summary of each expert's judgements are provided at the end of each round of assessment, helping

convergence towards a group consensus as experts consider the views of others and are given opportunities to revise their earlier judgements.

Decision tree: This method provides a temporal cause-and-effect map of all possible dynamic outcomes associated with each potential decision. This approach requires the discretisation of all continuous variables, which leads to an exponential increase in the size of the decision tree as the number of decision variables and random outcomes increases.

Bayesian networks: These models consist of a qualitative diagram that maps the relationships between nodes of the network and conditional probabilities that quantify how a change in related elements flows through the network. Bayesian networks provide an efficient description of large joint probability distributions, while also using the tools of Bayesian inference (Borb and Nicholson, 2010) to allow the probabilistic outcomes of various independent actions to be estimated. Unlike causal-loop diagrams and fuzzy-logic mapping, Bayesian networks are not suitable for representing feedback loops between two or more elements of the system.

Influence diagrams: These formalisms extend Bayesian networks to include decision variables and functions that reflect how actions and outcomes influence the expected utility of decision makers. The definition of variables as continuous, rather than discrete, entities in influence diagrams means that the model size does not become unwieldy as it grows, in contrast to the use of decision trees (see above).

Stock-and-flow models: Stock-and-flow models are typically applied in the field of system dynamics, as an extension to the use of causal-loop frameworks. As their name suggests, they are dynamic models that focus on quantities (stocks) that persist across time and are influenced through in-flows and out-flows. The use of stock-and-flow models is typically justified through the reasoning that rehabilitation activity must be persistent in environmental systems, given that many natural resources are stocks that do not recover quickly, exhibit inertia, and may rapidly deteriorate if or when they cross certain thresholds (Clark, 1990).

Deterministic optimisation models: This method involves the automated selection of the set of decision variables that maximises or minimises some objective measure, but where all inputs are defined with certainty. This is done through the application of a solution algorithm to a mathematical statement of a problem. A typical economic model developed in the context of environmental policy assessment in New Zealand will identify the hectares of different land uses and the intensity of mitigation required in each land use that meets the required level of environmental improvement at least cost.

Robust optimisation models: This method involves the automated selection of the set of decision variables that maximises or minimises some objective measure, but where some or all inputs are defined as uncertain variables. Uncertainty is represented through membership to a uniform distribution that is defined only by its lower and upper bounds.

Stochastic optimisation models: This method involves the automated selection of the set of decision variables that maximises or minimises some objective measure (or measures). In these models, some or all inputs are defined through the inclusion of probability distributions. Many of these models focus on how best to update management decisions as information unfolds throughout time, for example multi-stage stochastic programming and stochastic dynamic programming.

Assessment

Table 1 provides an assessment of each of the frameworks in relation to the criteria outlined in ‘design criteria for assessment frameworks’.

Table 1. Assessment of each of the integrated frameworks relative to the set of design criteria (pages 7 and 8).

Framework	Typical resolution	Suitable for participation	Data type	Risk and uncertainty	Clarity of framework	Clarity of output	Reference
Benefit-cost analysis (BCA)	Small to medium	Low/medium	Quantitative	(Sensitivity analysis)	Medium	Medium	Boardman et al (2010)
Augmented BCA	Large	Medium/high	Qualitative and quantitative	(Sensitivity analysis)	Medium/high	Medium/high	Doole et al (2016a)
Probabilistic BCA	Small to medium	Low/medium	Quantitative	Risk and uncertainty	Low	Medium	Almansa and Martinez-Paz (2011)
Causal loop models	Small	High	Qualitative	(Sensitivity analysis)	High, could be complex	High, could be complex	Sterman (2000), Connolly (2017)
Fuzzy logic mapping	Small	High	Qualitative and quantitative	Risk and uncertainty	Medium, potentially complex	Medium, could be complex	Connolly (2018)
Policy graph	Small	High	Qualitative	Risk and uncertainty	Medium	Medium, could be complex	Dowson (2018)
Expert assessment	Medium/large	High	Qualitative and quantitative	(Sensitivity analysis)	High	High	Schindler et al (2014)
Delphi technique	Medium/large	High	Qualitative and quantitative	(Sensitivity analysis)	High	High	Mukherjee et al (2015)

Framework	Typical resolution	Suitable for participation	Data type	Risk and uncertainty	Clarity of framework	Clarity of output	Reference
Decision tree	Small	Medium/High	Qualitative and quantitative	(Sensitivity analysis)	High, could be complex	Medium	Gray et al. (2013)
Bayesian network	Small	High	Qualitative and quantitative	Risk and uncertainty	Medium, could be complex	Medium	Borb and Nicholson (2010), Chan et al. (2010)
Influence diagram	Small	High	Qualitative and quantitative	Risk and uncertainty	Medium, could be complex	Medium	Varis et al. (1990)
Stock and flow models	Small	High	Quantitative	(Sensitivity analysis)	Medium, could be complex	Medium, could be complex	Luna-Reyes et al. (2006), Turner et al. (2016)
Deterministic optimisation models	Large	Low	Quantitative	(Sensitivity analysis)	Low	Low/high	Doole (2016b, c)
Robust optimisation models	Large	Low	Quantitative	Uncertainty only	Low	Low/high	Doole and Pannell (2011)
Stochastic optimisation models	Large	Low	Quantitative	Risk and uncertainty	Medium, could be complex	Medium, could be complex	Kampas and White (2004)

Integrated assessment framework

The focus of this review is the integrated assessment of the economic, environmental, and socio-cultural effects of environmental management. This review is part of an overarching project that seeks to provide evidence of the anticipated social, economic, environmental, and cultural effects of proposed policy reforms, including the choice of inaction. In this context, the given framework needs to possess a number of features:

- Flexibility in terms of its ability to represent the impacts of management actions at various scales and at different levels of resolution. This is required because of continued uncertainty around what case studies will be utilised.
- The framework must cater for the inclusion of diverse perspectives and sources of data. This is required given the collaborative nature of modern environmental planning, particularly in the context of the National Policy Statement for Freshwater Management 2014.
- A suitable framework must consider both qualitative and quantitative data, given the goal to assess the social, economic, environmental, and cultural effects of proposed policy reform.
- An appropriate assessment methodology must allow for various levels of uncertainty and consider the differing relationships within the system of interest. The large size and significant complexity of the systems means that most data will be subject to high uncertainty, with little hope of reconciliation through scientific research.
- The framework must be clear and easy to understand, especially to those who are involved in its use and those who will utilise its output.
- The output of the model must be clear and understandable to those who will utilise it.

These diverse criteria narrow down the set of suitable measures. Overall, the expert assessment and Delphi approaches provide portable means to assess the broad impacts of policy reform, including in the business-as-usual case. Features that are particularly advantageous include:

- flexibility in terms of focus, scale, and study region
- suitability for involving people with diverse experience, knowledge, and perspectives
- ability to scale the exercise in response to the amount of data, expertise, money, and time available
- proactive approach towards risk and uncertainty
- capacity to deal with different indicators and metrics
- clear methodology and results
- recognition of the scarcity of scientific evidence with respect to many key relationships
- ability to build understanding and trust through utilising straightforward methodology and being able to consider broad perspectives

- extensive application in previous contexts (for example, Schindler et al, 2014; TLG, 2016).

A flexible process for structured expert assessment is outlined below:

- Identify experts in relevant areas.
- Work with experts to identify the scope of the analysis:
 - refine and agree on the objectives of the assessment
 - identify a case-study location
 - establish a baseline (compared to natural state, 1950, 1990, etc)
 - identify the type of impacts to focus on and group these into functional categories
 - agree on the process with experts and revise a draft approach
 - agree on the scoring system for each functional category
 - identify the intervention scenarios. (This is most relevant for a study focused on improving management.)
- Review the literature regarding the type of impacts that directly relate to a study. The review can be done by experts or others, depending on the amount of resources available.
- Provide the literature review to members of the expert panel, as a source of material to augment their personal experience and knowledge.
- Experts fill out a subset or all the scoring sheets, before meeting in person. A short one- or two-sentence justification is provided for each score.
- Summaries are made of the scores and justifications provided by each expert before the meeting.
- One or several facilitated workshops are held where experts are drawn together to discuss the individual answers. Experts can choose to change their scoring or leave it the same as provided earlier before the meeting. (During the meeting, the facilitator may attempt to establish consensus. However, overall, this may often be too difficult and/or too time-consuming.)
- Information is reported that summarises the process. This should include a description of the method, results, and the justifications provided by individuals and the group.
- The report should be reviewed by key experts. This process should focus on consistency, and also the enrichment of the document through the addition of material. It may be necessary to revisit judgments where it is shown to be inconsistencies in the evaluation.

This draft process can be revised as appropriate, but nonetheless provides an overview of an accessible and defensible process for assessment.

Conclusions

The integrated assessment of a broad range of diverse impacts is a challenge for environmental management. This stems from uncertain scientific evidence and strong value conflicts. This review provides a summary of many diverse methods, ranging from straightforward expert-led assessment to highly-technical optimisation models. Their suitability is assessed with respect to a set of key design criteria identified as central to the effective integrated evaluation of a broad range of anticipated social, economic, environmental, and cultural effects arising from environmental management.

Overall, it is believed that an expert-led integrated assessment provides credible and flexible frameworks for proactively dealing with the severe uncertainty facing decision-makers. A draft adaptive process is generated for guiding further discussion.

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