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Surveys

A survey of decision-making approaches for climate change adaptation: Are robust methods the way forward?

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A B S T R A C T

Applying standard decision-making processes such as cost–benefit analysis in an area of high uncertainty such as climate change adaptation is challenging. While the costs of adaptation might be observable and immediate, the benefits are often uncertain. The limitations of traditional decision-making processes in the context of adaptation decisions are recognised, and so-called robust approaches are increasingly explored in the literature. Robust approaches select projects that meet their purpose across a variety of futures by integrating a wide range of climate scenarios, and are thus particularly suited for deep uncertainty. We review real option analysis, portfolio analysis, robust-decision making and no/low regret options as well as reduced decision-making time horizons, describing the underlying concepts and highlighting a number of applications. We discuss the limitations of robust decision-making processes to identify which ones may prove most promising as adaptation planning becomes increasingly critical; namely those that provide a compromise between a meaningful analysis and simple implementation. We introduce a simple framework identifying which method is suited for which application. We conclude that the 'robust decision making' method offers the most potential in adaptation appraisal as it can be applied with various degrees of complexity and to a wide range of options.

1. Introduction

Climate change adaptation research has progressed significantly in the last decade, illuminating many different aspects in the field, including identifying potential adaptation options (Iglesias et al., 2012), exploring impacts under different scenarios (Stern, 2007) and identifying relevant governance challenges in policy decisions (Huntjens et al., 2012; Pahl-Wostl, 2009). But relatively few adaptation actions have actually been implemented (Wise et al., 2014). At the same time, climate change projections highlight the likelihood that humankind will have to prepare for severe changes: the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013) indicates that warming trajectories of global temperature will likely exceed two degrees by 2100 and a World Bank report (Worldbank, 2012) projects that the planet is on track for a four degree Celsius warmer world by 2100. These reports go beyond the conceptualisation of climate change adaptation, making an emphatic call for adaptation actions in the present. Adaptation in many sectors will be reactive as the time frame for many decisions is too short to take into consideration the long-term climate signal. Adjusting growing seasons in agriculture according to changes in climatic conditions is a classic example. A farmer can implement such changes on a yearly or seasonal basis observing the prevailing weather. But implementing such incremental adaptations may not be sufficient in the long term, when anticipatory and planned adaptation is required; for example large infrastructure projects with long life times such as urban drainage structures, dams or sea walls. In some cases, society will want to avoid threshold events, such as the extinction of certain species. Moreover, extreme events may become more frequent and intense with climate change (IPCC, 2012), which may also necessitate intervention now. Where anticipatory adaptation leads to a situation in which the system is over- or under-adapted to the future climate outcome, additional costs are incurred either through large residual climate change impacts, the waste of investment if changes are not as severe as projected, or through the failure to seize new opportunities arising from climate change. Fankhauser (2009) reviewed different studies of adaptation costs whose estimates range from around $25 billion a year to well over $100 billion for the next 20 years based on 'median' climate change. Considering that the impacts of climate change might only become more severe in the more distant future, these costs may be an underestimation, but also show the inherent uncertainty of the costs of adaptation. In the context of a global economic crisis that is only slowly receding, a fortiori the allocation of significant resources to adaptation needs to be carefully scrutinised to invest wisely in appropriate options. Economists strive to give investment recommendations that minimise costs and maximise benefits. In other words, to allocate resources optimally by finding the strategy that is better than any other alternative for a given situation. Decision makers largely still use traditional economic analysis techniques for appraising

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adaptation investments, predominantly cost–benefit analysis (CBA), which struggles to account for uncertainty. Methods that extend these tools are increasingly being discussed but applications remain relatively scarce. In this paper, we progress the existing literature on these techniques by providing a decision-making framework to guide decision makers to the most appropriate appraisal method for their situation. We also indicate which robust methods may prove most promising as adaptation planning becomes increasingly critical.

We first summarise traditional decision-making approaches to appraise investment, describing briefly cost–benefit analysis, cost–effectiveness analysis and multi-criteria analysis, followed by the difficulties of applying these methods in the context of climate uncertainty. Section 3 then presents the conceptual basis of decision-making approaches that deal better with uncertainty, so-called robust methods. The overview is not exhaustive: it describes the methods and tools that are currently most discussed in the adaptation literature and in other taxonomies of decision-support approaches (Hallegatte et al., 2012; Herman et al., 2014; Jones et al., 2014; Kunreuther et al., 2014). We focus in particular on the underlying assumptions of these methods and on the conditions under which the methods work well, and illustrate each method with a number of applications from the literature. Subsequently, we provide a simple framework summarising which adaptation problem is best appraised by which decision-making process. In Section 4, we extend the discussion on robust methods by describing the limitations of robust decision-making methods, reflecting on why they have so far not been more widely applied in real projects. Finally, we outline the potential future direction of research for robust methods, identifying which may prove most promising for policy making; namely those that find a compromise between a meaningful analysis and simple implementation.

2. Traditional decision-making approaches

Cost–benefit analysis, cost–effectiveness analysis and multi-criteria analysis are widely used decision-making approaches in policy analysis when appraising projects.

Cost–benefit analysis (CBA) attempts to maximise the benefits for society based on potential Pareto efficiency.[1] It assesses whether it is worthwhile to implement a project by comparing *all* its monetised costs and benefits expressed over a defined time span to obtain its net present value (NPV) as in Eq. (1):

$$\mathrm{NPV}(i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \qquad (1)$$

where N is the total number of periods, i the discount rate, t is time and R_t is the net benefits (benefits minus cost) at time t. For CBA in adaptation, climate change impacts and their value must first be estimated. For this, climate projections from coupled ocean/atmosphere general circulation models (OA/GCMs) under a range of greenhouse gas emission scenarios are downscaled. This output is then fed into impact models to determine for example changes in rainfall of or crop yields. Subsequently, the impact following the adaptation option must then also be valued, and the difference between pre- and post-adaptation impacts provides the net benefits of adaptation R_t. Additionally, the costs of adaptation must be estimated over this time period. Fig. 1 illustrates how adaptation benefits are obtained.

The stream of benefits and costs over time is discounted to present values, and a net present value (NPV) is calculated by subtracting the net costs (cost of adaptation measure) from the net benefits (pre-adaptation minus post-adaptation impacts, thus avoided damages). A positive NPV indicates that the project should generally proceed (Boardman et al., 2014). Alternatively, if the ratio of benefits to costs ("benefit–cost ratio") is larger than one, the investment is economically desirable. Provided that reliable data on costs and benefits are available, CBA can be carried out with limited technical resources and the results are accessible to a non-technical audience (for applications, see for example Escobar (2011) and Willenbockel (2011)).

Cost–effectiveness analysis (CEA) represents an alternative to cost–benefit analysis when it is difficult or controversial to monetise benefits, such as the value of lives saved or landscape values. CEA compares mutually exclusive alternatives in terms of the ratios of their costs and a single quantified, non-monetised effectiveness measure with the aim to choose the least cost option. CEA is relatively straightforward in terms of optimisation: when effectiveness across all options is assumed to be identical it amounts to a simple cost minimisation problem such as achieving an acceptable level of flood protection. When the budget is fixed, an effectiveness maximisation problem is solved. For applications to adaptation, see for example Boyd et al. (2006) and Luz et al. (2011).

CEA works best if the benefits of the adaptation options are identical given one metric. This might apply with regard to clearly defined technical solutions. But if neither costs nor benefits are identical, scale effects need to be considered: policies with low impact at a relatively low cost per unit will be ranked higher than policies that have high impacts at a somewhat higher cost (Boardman et al., 2014) (see also Kunreuther et al. (2014) for further comparison of CBA and CEA in the context of climate policy).

Multi-criteria analysis (MCA) in its simplest application (whose complexity can be increased in various ways) usually consists of a combination of quantitative and qualitative (monetised and non-monetised) indicators that provides a ranking of alternatives based on the weight the decision maker gives to the different indicators (see for example Garcia de Jalon et al. (2013) for an application). For example, distributional or psychological impacts for which it is difficult to assign a monetary value can be integrated according to the preferences of the decision maker. Results from other methods such as cost–benefit analysis can be included (UNFCC, 2009). Through the weighting, the data is mapped onto an ordinal scale and both quantitative and qualitative data can be compared relatively, but not with regard to an absolute scale, prohibiting a generalisation of the results.

CBA, CEA and MCA have all long been tested, further developed and successfully applied to many projects and policies, but policy makers face considerable challenges when applying these decision-making approaches in an area of uncertainty such as climate change adaptation. While the costs might be observable and immediate, the benefits of adaptation are harder to define, as these require planning and foresight about how the climate will change. Indeed, there is considerable uncertainty attached to climate change projections, as well as to the expected impacts and responses to them (Dessai and van der Sluijs, 2007). In particular, uncertainty exists with regard to downscaled climate data such as localised data on precipitation, temperature and flood probabilities, which might not be resolved for a long time, if at all (Fankhauser and Soare, 2013). Uncertainty also stems from the future emissions of GHG, how global and local climate systems will react to these changes in emissions as well as the response of other systems to climate change, including ecosystems (Wilby and Dessai, 2010). Finally, there is uncertainty regarding knock-on effects on society and the economy depending on their vulnerability and adaptive capacity (Kunreuther et al., 2012).

These unknowns make the application of the decision-making approaches described above at least in their 'basic' formulation challenging. The uncertainty can be addressed in different ways. For example, an expected values framework attaches "subjective probabilities" (Hallegatte et al., 2012), to evaluate the expected benefits as the probability-weighted average of the benefits based on how likely different states of the world are (Gilboa, 2009). Probabilities can be based on past occurrences of events, expert knowledge, or both. Subsequently projects matching the conditions of that future are designed and fine-tuned with sensitivity analysis. Similar to this is expected utility—if

[1] An allocation is pareto efficient if no alternative allocation can make at least one person better off without making anyone else worse off.