Handling deep uncertainties in impact assessment

Wil A.H. Thissen and Datu Buyung Agusdinata
Faculty of Technology, Policy and Management,
Delft University of Technology, Delft, Netherlands
E-mail: Thissen@tbm.tudelft.nl

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Abstract
Uncertainties abound in impact assessment, not just because a lack of knowledge or theory, but also because impact assessment is about the future. Yet, little attention is given to this very important aspect, and this regards both the systematic identification and assessment of uncertainties, and design of adequate policies in light of uncertainty. In many situations uncertainty cannot be easily reduced by doing more research. This paper outlines a number of different approaches to dealing with uncertainties, and briefly introduces a novel analytic approach (called 'Exploratory Modeling and Analysis') to analyzing situations where uncertainties are multiple and cannot easily be quantified.

Introduction

While scientists and (most) policy and decision makers would often like certainty about the various relevant consequences of proposed policies, programs, plans and/or projects, the reality is that the estimation of such impacts is subject to significant uncertainty. First, because our knowledge of the current states of the ecological, economic, and social systems, and of the mechanisms governing their change is limited. Second, because impact assessments are about the future, which brings unforeseen, often even unforeseeable developments.

Despite the omnipresence of uncertainties, relatively little attention so far has been given to this important aspect of impact assessment. Generally, the tendency, driven by scientific motives and supported by decision maker wishes, has been to invest in deeper or more detailed research in hopes of reducing uncertainties. But many such uncertainties cannot easily be reduced. In such situations, it may be advisable to *accept* uncertainties, and spend efforts on identifying and assessing them and on developing appropriate approaches to act in light of (irreducible) uncertainties. Firstly, because it is ethically undesirable to present impact assessment results as if they were certain, or with only limited attention to uncertainties. Secondly, awareness and assessment of uncertainties can help in making more deliberate choices among given alternatives in light of uncertainties, and/or in designing new alternatives that are specifically oriented to the uncertain environment.

In this paper, we will briefly outline some of the current approaches for identification and assessment of uncertainties, and strategies to deal with them. Subsequently, we will focus on a novel approach called Exploratory Modeling and Analysis, particularly oriented towards dealing with so-called deep uncertainties in an analytical way.

Approaches to dealing with uncertainty: a rough overview

Traditional risk- and probability-based approaches based on mostly mathematical modeling concepts, have been popular in the natural and engineering sciences, and in the safety sciences. However, awareness of the need to pay attention to a broader class of uncertainties has been growing over the last decades, not in the least because in many cases uncertainties that cannot easily be quantified may be more influential than those that can – and this is particularly the case in long-term strategic policy settings. Various authors have given attention to more fundamental discussions about sources and typologies of uncertainties (e.g. Walker et al., 2003 ; Van Asselt, 2000), ways of assessing them (e.g. Funtovicz and Ravetz, 1990; Morgan and Henrion, 1992), and to approaches to decision making under uncertainty (e.g. Dewar et al., 1993; Klinke and Renn, 2002; Walker et al., 2001).

Generally speaking, the literature confirms the relevance of probability-based approaches in situations where sufficient knowledge is available about the possible impacts of a policy or decision, and about their probabilities of occurrence. The literature also increasingly recognizes the importance of other uncertainties, those that cannot easily be captured in terms of probabilities, for example, when merely the *possibility* of some developments or surprise events is acknowledged (such as in economic development scenarios). In addressing such other classes of uncertainties and ways of dealing with them, various authors introduce slightly different typologies and terminologies, and a unified and agreed upon classification of uncertainty sources and types, and ways of best dealing with them, has not been reached yet.

For practical purposes in this short paper, we distinguish between *analytic approaches* for identifying and assessing uncertainties on the one hand, and *policy or decision strategies* in light of uncertainties on the other, building on the classification as given in (Van Geenhuizen and Thissen, 2002).

Leading questions for *analysis* of uncertainties include: What are the primary sources of uncertainty? How large are these uncertainties? Which are the most important ones, and how important are they, in light of the decisions to be made? Methods to identify and assess uncertainties include determination of confidence bounds for data and model parameters; probabilistic approaches; sensitivity analysis; scenario approaches (e.g. Schwartz, 1997; Bayer and Yeomans, 2007); development of alternative system models to account for alternative structures; or combined approaches such as the so-called NUSAP method (Funtowicz and Ravetz , 1990, see also www.nusap.net) .

Among the policy or *decision strategies* to *act* in light of uncertainty, we distinguish four fundamentally different approaches:

- To *ignore* uncertainty, make a decision, and see what will happen; while this may be the easiest option, it means accepting large uncertainty with respect to the eventual decision outcomes and could lead to disastrous outcomes.
- To *delay* the decision and let uncertainty be reduced by time; this approach involves a good chance that, while some uncertainties will disappear, new ones will emerge – and, conversely, that opportunities that could have been grasped by quick action may be foregone.
- To *reduce* uncertainty. This can be done in different ways:
    - by 'buying information' through additional research or better integration of existing knowledge.

  - by pushing the uncertainty onto someone else, which generally will involve costs (e.g., insurance premiums, compensation)
  - by negotiating with others whose behavior or preferences are uncertain but may have significant impacts on the desired policy outcomes. Such process or discursive approaches are also advocated in cases where uncertainties are related to differences in actor perceptions or values (e.g. Klinke and Renn, 2002; Koppenjan and Klijn, 2004).
- To *accept* uncertainty, and *act consciously* in its presence. Here, too, different strategies are possible:
  - Choosing an option according to one's attitude towards risk; for example, a risk adverse person would prefer not to choose an option the outcomes of which are uncertain, while a risk prone person would be in for a gamble.
  - Selection of a robust decision, i.e., a decision that will do well in most possible future circumstances;
  - Design of an adaptable decision or policy, i.e., a policy that is flexible enough to be adapted in time as the future unfolds (e.g. Walker et al., 2001). The need to be flexible and adapt is also emphasized in so-called process approaches, where interaction and learning are key to adaptation (Koppenjan and Klijn, 2004).

Clearly, these options for acting do not exclude each other. Parts of the efforts may be directed to reducing some of the uncertainties, other parts to designing an appropriate strategy where uncertainty cannot easily be reduced. Moreover, in order to act consciously in light of uncertainties, it is necessary to have an idea of how large the uncertainties are, what their origin is, and how they may affect the decision outcomes. For a more elaborate overview of approaches to uncertainty assessment, and frameworks for decision making under uncertainty, we refer the reader to a recent report on uncertainty and climate change adaptation (Dessai and Van der Sluijs, 2007).

Exploratory Modeling and Analysis for situations of deep uncertainty

For many Impact Assessment situations, appropriate agreed upon theories and models about the relevant impact causing mechanisms are not available, let alone probability distributions for key parameters in the models. Moreover, parties will value the outcomes of alternative decisions differently. Such situations have been labeled as characterized by *'deep'* uncertainty (Lempert et al., 2003). Exploratory Modeling and Analysis (EMA) has been proposed as an appropriate analytic approach for such situations (Bankes, 1993; Lempert et al., 2003, Agusdinata, 2008).

The principles of EMA are similar to those underlying model-based sensitivity analysis and scenario-approaches. The basic idea of EMA is to exploit the ample availability of computing capacity to explore a wide uncertainty space in order to find out where in that space each policy option works or fails, and why. The approach extends beyond usual practice in that:

- the variety of assumptions on model relations and parameter values included in the analysis is wider;
- in principle, the possibility of multiple model structures is taken into account.
- a wide range of possible exogenous developments is taken into account whereas explorations in a 'normal' scenario approach are typically limited to three or four different scenarios

- ranges of assumptions explored are based on possibility, not probability.

Using computer capacity, numerous (up to 10.000 and more) samples are taken from the set of possible assumptions, and the impact of alternative policies is explored for all of these. Next, the generated output data are analyzed to explore the regions in uncertainty space where specific policies are successful or fail, thus providing insight in the robustness of policies, and in the regions ('mine fields') to avoid if possible when choosing a specific policy.

Illustration: CO2 emissions from residential heating

Based on a recent application details of which may be found in (Agusdinata, 2008; and Agusdinata et al., 2007), we illustrate part of the approach using the example of policy design to reduce CO2 emissions caused by residential heating. These emissions are determined by a variety of factors, including the state of home insulation, the efficiency of the heating technology used, dwellers' heating requirements and practices, the number of households, and the CO2 content of the heating resource used. For the sake of simplicity, in the case study natural gas was assumed to be the prime energy source for home heating, as is the case in the Netherlands. Policy instruments available include subsidies and/or tax incentives for stimulating energy efficiency refurbishments in housing buildings, subsidies for stimulating heating technology innovation and development, and setting standards for the energy efficiency of newly built dwellings. In an analysis designed to explore the impacts of alternative policies on CO2 emissions up to the year 2050, a relatively simple model was used, and the following key uncertain factors were taken into account:

- the future development/improvement rates of four different heating technologies
- the annual growth rates of gas and electricity prices
- the demolition rate of (old) housing
- various parameters affecting technology adoption/replacement decisions by home owners including the discount rate, and the acceptable payback period
- household size and population growth

Feasible value ranges (based on what could be possible, not probable) were set for the various uncertain factors, and a large number (50.000) computer runs were made with the model, each run representing a sample of the uncertainty space. Sampling was such that the whole space was covered. From the outcomes, a number of insights were obtained:

First, for a given, specific policy parameter setting, the range of possible resulting CO2 emission trajectories over time was identified, with projected CO2 emissions in 2050 ranging from about the same to ¼ of present emissions. Second, the sets of conditions under which a specific policy target (e.g., a 50% reduction in total emissions) may be realized were identified (all according to the model, of course). Such insights can be used as a basis for identifying assumptions critical to the success of a specific policy. For example, if the rise of the gas price is relatively low, a specific reduction of CO2 emissions can only be reached if technology progress is rapid and the demolition and replacement rates of old housing exceed a certain threshold value.

Time will reveal whether such conditions will become real or not. Monitoring the actual developments over time will then show whether or not the necessary conditions for success develop. If not, adaptation of policy measures is called for, and the analysis results indicate what adaptation is necessary to achieve the targets.

Concluding remarks

Despite the presence of deep uncertainties in many impact assessment situations, relatively little attention has been given to assessing such uncertainties to the extent possible, and to act deliberately in light of often irreducible uncertainties. Extending sensitivity analysis and (qualitative) scenario approaches (which are generally restricted to a limited set of scenarios), Exploratory Modeling and Analysis provides an interesting approach for situations where the most dominant uncertainties can be captured in relatively simple models. It provides insight into a wide range of possible assumptions about future developments and the outcomes resulting from these, and can therefore assist in developing policy principles that either avoid the worse outcomes, or that are flexible enough to be adapted when certain circumstances realize.

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