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Portfolio decision analysis methods in environmental decision making

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ABSTRACT

Environmental modellers recurrently work with decisions where a portfolio of actions has to be formed to effectively address the overall situation at hand. When creating the portfolio, one needs to consider multiple objectives and constraints, identify promising action candidates and examine interactions among them. The area of portfolio decision analysis deals with such tasks. This paper reviews portfolio modelling approaches and software that are applicable in environmental management. A framework for environmental portfolio decision analysis is provided that consists of steps ranging from problem framing to modelling and optimization, as well as to the analysis of results. The use of this framework is demonstrated with an illustrative case describing planning of urban water services. The problem is analyzed with a recently introduced portfolio decision analysis method called Robust Portfolio Modelling, which enables the use of incomplete preference information and consequence data. This feature can be particularly useful in environmental applications.

Software availability

Name of the software: RPM-Decisions
Requirements: Windows 7–10, Java runtime environment
Contact: http://rpm.aalto.fi

1. Introduction

Environmental management decisions are often portfolio problems where the task is to find a portfolio of actions to meet the overall objectives, targets, and constraints. For example, when the goal is to cut greenhouse gas emissions by a certain amount, the decision makers seek to identify a portfolio, i.e. a combination of actions, whose combined effects result in reaching the target reduction level. The actions can be, e.g., energy saving measures, investments in renewables, educational projects, technology development, or regulation policies. Typically, the decision makers also have to consider the overall performance of the portfolio across other relevant dimensions or criteria, such as, costs, social and political impacts, as well as environmental risks. In this paper the following terminology is used. Attributes refer to the measures used to describe the consequences of alternatives. Objectives refer to higher level goals. In the literature attributes are sometimes called criteria. This paper uses the term multi-criteria evaluation when referring to decision analysis approaches where alternatives are evaluated with respect to multiple criteria.

In practice, environmental portfolio problems are often addressed so that experts first generate a number of feasible portfolio alternatives, which are combinations of actions that satisfy the overall requirements. These alternatives are then compared by stakeholders using multi-criteria evaluation to identify the most preferred one. The quality of the resulting decision naturally depends on the experts' ability to initially construct good portfolio alternatives. This task is particularly challenging when the number of action candidates is high and there are many conflicting objectives. There can also be non-linearities or interactions across the set of actions and their consequences. If this is the case, the overall performance of a combination of actions is not necessarily the sum of the action specific performances. Surprisingly, the extensive literature on environmental multi-criteria decision making has so far given very little attention to the possibilities offered by portfolio modelling (see, e.g. Linkov and Moberg, 2011; Huang et al., 2011; Gregory et al., 2012).

The current paper contributes to the literature by making the portfolio approach more easily accessible. This paper explains how the emerging area of portfolio decision analysis (PDA; Salo et al., 2011) can benefit the practitioners and researchers in

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environmental management and decision making. A comparative description of five major portfolio modelling approaches is given. These approaches offer modelling and optimization support to find the best portfolio of actions or the non-dominated portfolios. The final choice of a portfolio should be made among the non-dominated portfolios. If a portfolio is dominated, there exists another portfolio of actions, which is better in some attribute and at least equally good in all other attributes. The model based portfolio generation process advocated here can help to consider multiple objectives and resource constraints, interactions related to the actions, as well as uncertainties. The portfolio perspective can also help mitigate the overall risk related to a set of actions (see, e.g. Keisler and Linkov, 2010; van der Honert, 2016).

This paper develops a general framework for environmental portfolio decision analysis which aims at providing environmental researchers and practitioners an easy entry into implementing decision processes that utilize portfolio models. The use of the framework is demonstrated with an illustrative case related to urban water service planning (Mitchell et al., 2007). The case is analyzed using the recently introduced portfolio decision analysis method called Robust Portfolio Modelling (RPM; Liesiö et al., 2007), which enables the use of incomplete preference and consequence information (Salo and Hämäläinen, 1995). This possibility can be useful in environmental management problems. Perfect data about the environmental impacts of the action candidates is rarely available. The stakeholders may not want to give exact numbers to represent their opinions on the relative importance of each decision objective.

The framework described in this paper incorporates elements from both top-down and bottom-up decision support approaches (see, e.g. Montibeller et al., 2009; Linkov et al., 2014). The first phase within the framework is to describe the overall problem and goals. This represents the top-down perspective. The idea is to direct the problem solvers to reflect on the desired overall consequences. Having the big picture in mind can often help in generating new action candidates (Keeney, 1992). The bottom-up perspective, in turn, is naturally present almost always in environmental problem solving processes: When a problem solving project is set up, it is often based on the existence of some already available action candidates. In addition, the stakeholders usually bring with them their own ideas of actions, which are related to their interests. One major contribution of the portfolio approach is that all action candidates can be included in the same analysis. The participants and stakeholders can easily bring their ideas and possible actions to the table. This is likely to increase the participants' commitment to the problem solving process and create a sense of shared ownership of its outcomes, which is important in environmental problem solving (Voinov et al., 2016).

So far, the main areas in the environmental management literature where portfolio modelling has been used are conservation network design and investment decisions related to the development of natural capital and ecosystem services. Conservation network design problems typically include a very high number of actions, which relate to areas of land to be included in the network (see, e.g. Ando et al., 1998; Possingham et al., 2000; Moilanen, 2007; Kreitler et al., 2014). A similar setting is encountered in conservation auctions where landowners bid pieces of land to be included in conservation networks and the decision makers need to choose which pieces of land to purchase (see, e.g. Hajkowicz et al., 2007). Models related to environmental investments typically deal with the problem of choosing a set of costly improvement or restoration actions with uncertain outcomes (see, e.g. Hajkowicz et al., 2008; Higgins et al., 2008; Marinoni et al., 2009, 2011). These studies employ a variety of approaches based on multi-criteria evaluation, optimization, multi-objective optimization, benefit-cost analysis and modern portfolio theory. Yet, the opportunities to utilize portfolio approaches in environmental management problems are much wider. Many environmental multi-criteria decision making processes include an implicit portfolio generation stage in creating the alternatives. The ideas and the framework presented in this paper help to include the portfolio approach explicitly already in the initial stages of these processes.

The paper is structured as follows. Section 2 discusses behavioral issues in unaided portfolio generation. Section 3 provides an outlook on different portfolio modelling approaches. Section 4 introduces a framework for environmental portfolio decision analysis. Section 5 provides the illustrative example demonstrating both the framework and the RPM approach and software. Section 6 discusses software support for portfolio decision analysis. Section 7 summarizes our conclusions.

2. Behavioral issues in portfolio generation

Behavioral issues can easily arise when the problem solving team generates portfolio alternatives. The task is complex and there can be behavioral biases originating from, e.g., motivational, social, and cognitive phenomena (Fasolo et al., 2011). The outcome of an unaided portfolio generation process is likely to be path dependent (Lahtinen and Hämäläinen, 2016; Hämäläinen and Lahtinen, 2016; Lahtinen et al., 2017), i.e. depend on the starting point and the order in which different actions are considered. For general discussions on behavioral issues in operations research and environmental modelling, see Hämäläinen et al. (2013) and Hämäläinen (2015).

The traditional approach (Fig. 1) used in environmental portfolio problems is that the problem solving team generates portfolio alternatives to be compared against each other with multi-criteria evaluation (see, e.g., Marttunen and Hämäläinen, 1995; Prato and Herath, 2007; Linkov and Moberg, 2011, p. 144; Gregory et al., 2012, pp. 155–171). These alternatives are typically constructed in a stepwise process where new actions are included into a portfolio following the feedback obtained from the stakeholders. The goal is to generate combinations of actions, which are non-dominated with respect to the criteria. In such a process there is a risk that there are better portfolios, which are not found and are left out of the evaluation.

Paying attention to the overall performance of each portfolio can be an overwhelming challenge in portfolio generation without modelling and optimization support. There can be many action candidates, multiple objectives, and interactions across the actions and their consequences. Interactions can relate to the effects of the actions, to their resource consumption, and give rise to constraints that prevent some of the actions to be jointly included in the same portfolio (see, e.g. Fox et al., 1984). Due to interactions, the consequences of an action can depend on other actions included in the portfolio. For instance, emissions from cars can be reduced by developing improved emission reduction technologies or by reducing the total miles driven. The effect of reducing the miles driven clearly depends on the technology available for the emission reductions in the cars. It can be very difficult to consider such interactions without computational support. For example, the well-known climate wedge game (http://cmi.princeton.edu/wedges/game.php) based on Pacala and Socolow (2004) includes such interactions. Furthermore, if actions are considered and added in the portfolio one at a time, it can happen that only those actions are selected, which score well in every attribute. Yet, it can be a mistake to discard an action which is weak in some attributes but has strong positive impact across the other attributes. The right choice can be to select such actions into the portfolio and compensate their weaknesses with some other actions.

Path dependence (Lahtinen and Hämäläinen