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How do you perceive environmental change? Fuzzy Cognitive Mapping informing stakeholder analysis for environmental policy making and non-market valuation

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ABSTRACT

In spite of considerable progress in our understanding of ecosystem functioning, our ability to design effective and enforceable environmental policies requires a deep understanding of human perceptions and beliefs. In this respect, what is called today stakeholder analysis is an eclectic mixture of qualitative and semi-quantitative techniques aiming at eliciting, understanding and de-codifying how individuals perceive risks and threats towards sustainability. Fuzzy Cognitive Mapping (FCM) is gradually emerging as an alternative methodology capable of assisting researchers in the domain of environmental policy. We explored the promise that FCM holds to support environmental policy makers. We suggest FCM approach as a new participatory method in environmental policy: through aiding in Multi-stakeholder (actor) analysis for risk assessment, capturing values and scenarios construction. To show how this is feasible we try to answer three basic questions: How cognitive mapping can support decision-making? How FCM can support environmental decision-making? How simulation of concepts may help in communicating stakeholders' views to environmental decision makers? Then we explore the potential application of FCM in environmental policy, especially in environmental economics, trying to substantiate economic values for nature providing 'flesh and bones' to the concept of economic preferences.

1. Introduction

In the wake of 21st century, conserving natural resources and protecting climate stability is still unfinished business. Though this is true for pollution problems of the first generation (e.g. urban air pollution, solid waste and water pollution) the environmental problems our societies now face are of a more subtle and pervasive nature, e.g. global warming, habitat degradation and species loss, collapse of renewal resource stocks, land contamination – an endless suite of complex issues demanding a stronger commitment, a better science and a heavier financial burden. A number of biophysical indicators published by international agencies document this trend while environmental degradation appears intrinsically linked with issues of human rights, national security, human health and poverty [1–3].

In spite of our success in modelling and predicting impacts of man-made pressures on terrestrial and marine ecosystems, uncertainty of intensity and timing of impacts still looms large. A prominent domain full of uncertainties is climate change where low probability, high impact events – conceived as 'tipping points' [4] – pose risks of extreme magnitude for continuation of our civilization as we know it. What analysts have termed 'statistical undecidability' [5] seems to apply not only to world markets but also to climate change reality as well. New methodological tools are needed transcending the established divide between social and natural sciences, facts and values, objective forecasts and subjective visions.

Our institutions are still inadequately equipped for addressing these challenges. Therefore, the need for informed policies is urgent and a plea for a holistic approach to scientific problem solving is emerging. This is especially true for environmental policies supporting critical ecosystem process whereupon the very essence of our existence depends. Formulation of a successful environmental decision-making relies on integrated models of socio-economy and the natural environment able to provide decision-makers with flexible and adaptive policies. According to [6], creating 'adaptive policies' could help policy-makers to navigate within today's complex, dynamic and uncertain fields [7] identifies the persisting gap between environmental experts and policy makers. Discussing the future use of actor analysis in environmental policy analysis the author proposes three plausible explanatory mechanisms for his 'rather disappointing result' regarding the role of actor analysis in water management: project and institutional path dependence, the

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preferences of experts for their own professional tools and expertise and the manner environmental experts perceive their role as issue advocates [7].

An ever growing number of practitioners see a way out of the ensuing dilemmas in opening up the process of designing effective policies in two directions: on the one hand, experts are called upon to provide their judgements and informed guesses in filling scientific information gaps. Eliciting expert judgements are nowadays widely practiced in the domains of climate, biodiversity and energy policy [8]. Expert judgement elicitation though has certain disadvantages (i.e. cost and time required, lack of flexibility, possible loss of creativity and the appearance of a false objectivity), which might cause results to be accepted without a prudential degree of scepticism [9].

On the other hand, researchers apply deliberative or inclusive approaches, which promise an integration of stakeholder groups into policy design and evaluation. On several occasions it has been shown that stakeholder values are the key to a structured decision approach to public involvement [10–13]. Stakeholder values identify what matter to participants and in turn highlight the consequences that require most careful attention and the trade-offs that matter most [14]. According to [15], meaningful involvement in the decision making process requires not only an invitation to participate but also a forum for careful deliberation and a mechanism for incorporating the results of technical analysis. New problems though arise when applying deliberative or inclusive approaches: How useful are lay people perceptions? Do we need welfare related perceptions only or should we investigate also perceptions on ecosystem functioning? How to incorporate perceptions into decision-making? How to extract useful local knowledge? What to disregard? How to cope with biases due to the elicitation approach? How to quantify? How to treat qualitative information? To tackle these challenges appropriately within an ecosystem-based approach, current environmental management strategies need to 'navigate' through an apparent tension: they must meet the demand for scientific knowledge-based policy, while the very same strategies urge for stakeholder involvement and sponsor initiatives to elicit lay-people attitudes, beliefs and visions for the future. This tension seems to reflect the everlasting standoff of bottom up and top down approaches.

Deliberative or inclusive approaches to environmental management are usually referred to as 'stakeholder analysis' [16–18]. Stakeholder analysis includes mostly qualitative approaches that refer to the interaction of social groups and their dynamics: social network analysis [19–21], analysis of conflicts [22–25] and actor analysis [7]. It also includes qualitative or semi-quantitative approaches exploring individual perceptions, values and attitudes. These include: comparative cognitive mapping of social perceptions and values [26,27], perceptions mapping [28], mind mapping [29], concept mapping [30], focus groups and in-depth interviews. Approaches in stakeholder analysis as described above share some common characteristics: they are eclectic but pragmatic approaches with varying degree of sophistication, requiring in average a low in-depth academic investigation, but able to manipulate a vast quantity of soft information using interviewer survey-based methods for eliciting and recording their data.

The present paper focuses on Fuzzy Cognitive Mapping (FCM), a promising supplement to areas of environmental policy such as participatory environmental scenario development, subjective risk analysis and stated preference approaches in environmental valuation. The paper raises some fundamental questions referring to the application of FCM in environmental management. It investigates meaningful questions rather than providing tailor-made solutions. In Section 2 a concise introduction to the FCM methodology is provided before we embark in Section 3 on the discussion of three questions related to specific aspects of FCM application in environmental management. The questions are chosen so as to illustrate basic challenges faced by an environmental policy researcher in his/her attempt to get the best out of FCM within social environmental research. Section 4 interrogates the applicability of FCM in the specific domain of estimating economic values for nature. The concluding Section 5 summarizes the insights gained and proposes areas of future research.

2. The FCM methodology

Proposed in 1986 by Kosko, Fuzzy Cognitive Maps are fuzzy signed graphs, which can be presented as an associative single layer neural network [31,32]. They describe particular domains using nodes (also known as concepts), and signed fuzzy relationships between nodes. The fuzzy part permits degrees of causality, represented as links between the concepts of these diagrams. This structure establishes the forward and backward propagation of causality, allowing the knowledge base to increase when concepts and links between them are increased.

Each of FCM's edges is associated with a weight value that reflects the strength of the corresponding relation. This value is usually normalized to the interval $[-1,1]$. The matrix E stores the weights assigned to the pairs of concepts. We assume that the concepts are indexed by subscripts i (cause node) and j (effect node). In the simplest case, it is possible to distinguish binary cognitive maps (BCM) for which the concept labels are mapped to binary states denoted as $Ai \in \{0, 1\}$, where the value 1 means that the concept is activated. The weights of BCM are usually mapped to the crisp set, i.e. $e_{ij} \in \{-1, 0, 1\}$. The value 1 represents positive causality, meaning that the activation (change from 0 to 1) of concept Ci occurs concurrently with the same activation of concept Cj or that deactivation (change from 1 to 0) Ci occurs concurrently with the same deactivation of concept Cj. The value -1 represents the opposite situation, in which the activation of Ci deactivates the concepts Cj or vice versa. The $e_{ij} = 0$ means that there are no concurrently occurring changes of the states of the concepts. Some researchers [33,34] assume that the elements on the diagonal of the matrix E are not considered. In FCMs, each node quantifies a degree to which the corresponding concept in the system is active at iteration step.

The development and design of the appropriate FCM for the description of a system requires the contribution of human knowledge. Usually, knowledgeable experts familiar with the FCM formalism are required to develop FCM using an interactive procedure of presenting their knowledge on the operation and behaviour of the system [35]. Experts and/or stakeholders are asked to determine the concepts that best describe the model of the system, since they know which factors are the key principles and functions of the system operation and behaviour, introducing a concept for each one. Experts have observed the operation and behaviour of the system during its operation, since they are the operators and supervisors of the system, who control it using their experience and knowledge. They have stored in their mind the correlation among different characteristics, states, variables and events of the system and in this way they have encoded the dynamics of the system using fuzzy if–then rules. Each fuzzy rule infers a fuzzy weight, which in procedure is translated to a numerical one used in the FCM reasoning process [36,37]. Fig. 1(a) and (b) shows a generic representation of the FCM model.

Once the FCM is constructed, it can receive data from its input concepts, perform reasoning and infer decisions as values of its output concepts [37–39]. During reasoning the FCM iteratively calculates its state until convergence. The state is represented by a *state vector* A^k, which consists of real node values $A_i^{(k)} \in [0, 1]$, $i = 1$,