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Review

Reviewing Bayesian Networks potentials for climate change impacts assessment and management: A multi-risk perspective

Anna Sperotto [a, b], José-Luis Molina [c], Silvia Torresan [a, b], Andrea Critto [a, b, *], Antonio Marcomini [a, b]

[a] Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), via Augusto Imperatore 16, I-73100, Lecce, Italy
[b] Department of Environmental Sciences, Informatics and Statistics, University Ca' Foscari Venice, Via delle Industrie 21/8, I-30175, Marghera, Venezia, Italy
[c] High Polytechnic School of Engineering, University of Salamanca, Av. de los Hornos Caleros, 50, 05003 Ávila, Spain

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The evaluation and management of climate change impacts on natural and human systems required the adoption of a multi-risk perspective in which the effect of multiple stressors, processes and interconnections are simultaneously modelled. Despite Bayesian Networks (BNs) are popular integrated modelling tools to deal with uncertain and complex domains, their application in the context of climate change still represent a limited explored field. The paper, drawing on the review of existing applications in the field of environmental management, discusses the potential and limitation of applying BNs to improve current climate change risk assessment procedures. Main potentials include the advantage to consider multiple stressors and endpoints in the same framework, their flexibility in dealing and communicate with the uncertainty of climate projections and the opportunity to perform scenario analysis. Some limitations (i.e. representation of temporal and spatial dynamics, quantitative validation), however, should be overcome to boost BNs use in climate change impacts assessment and management.

Contents

* Corresponding author. Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), via Augusto Imperatore 16, I-73100, Lecce, Italy.
E-mail address: critto@unive.it (A. Critto).

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1. Introduction

Climate change risk assessment represents a challenging task for environmental management due to the inherent complexity of socio-ecological systems, the multiplicity of processes and the high degree of uncertainty, variability and randomness involved (Döll and Romero-Lankao, 2017; Gallina et al., 2016).

Multiple climatic and non-climatic stressors interact, inducing impacts which can be highly correlated (i.e. cumulative, synergic or antagonistic effect) or strongly dependent (i.e. cascading or triggering effects) one each other (Gill and Malamud, 2014; Kappes et al., 2012; Liu et al., 2014). Neglecting these interactions can lead to an underestimation of the overall risk and further to inefficient or controversial risk management strategies (i.e. maladaptation, unexpected environmental impacts, increase vulnerability or exposure toward other kind of stressors) (Liu et al., 2014). An effective risk management should be built on a good understanding of all relevant threats affecting the target of interest thus enabling decision makers and practitioner to develop efficient adaptation plans based on a robust prioritization of risk reduction measures (Komendantova et al., 2014).

However, due to the differing characteristics of hazards, few quantitative models that suite a fully multi-risk perspective exist. Most climate change studies still are predominantly mono-disciplinary, designed to consider impacts triggered by individual shocks (i.e. hazards) and analyzing mono-causal and mono-temporal cause-effect relationships (Gallina et al., 2016; Næss, 2010).

At the same time, considering uncertainty as a pervasive issue in climate change, it should be included as a key component of each risk assessment model.

Despite this, most of risk assessment models still rely on the traditional definition of risk considering the probability of an event and its negative consequences (UNISDR, 2009). Instead, deep uncertainty about future risk could be better addressed by risk scenarios describing the range of plausible future environmental and socio-economic conditions (Döll and Romero-Lankao, 2017; Stirling, 2010; Willows and Connell, 2003).

The aforementioned considerations clearly suggest that climate change risk assessment and management, required a shift from traditional risk assessment based on a single stressor approach, toward a more challenging multi risk and adaptive paradigm (Döll and Romero-Lankao, 2017; Landis et al., 2013a).

New approaches should be included in the current environmental risk assessment and management procedures considering the adoption of integrated models (i.e. Bayesian Networks (BNs), System Dynamics (SD), Agent-Based Models (ABMs), Artificial Neural Networks (ANNs) and Expert Systems) able to: incorporate multiple stressors and endpoints (i.e. social, economic and environmental objectives and priorities); ii) deal with uncertainty; iii) take into account the effect of policy and adaptation in changing final system states (Hamilton et al., 2015; Kelly et al., 2013).

Bayesian Networks (BNs) in the last decade have become a recognized tool to deal with environmental problems and decision making under uncertainty (Varis and Kuikka, 1997) and some authors (Catenacci and Giupponi, 2010; Döll and Romero-Lankao, 2017; Hart and Pollino, 2008; Landis et al., 2013a; Pollino and Hart, 2008), suggested their use for risk assessment.

Bayesian Networks (BNs), also known as Bayesian Belief Networks (BBNs) or Belief Networks, are probabilistic graphical models representing a set of random variables and their conditional interdependencies via a Directed Acyclic Graph (DAG) (Pearl, 1988) thus using probabilistic expressions to describe the relationships among system components (Borsuk et al., 2004).

BNs, originally emerged from research into artificial intelligence (Charniak, 1991; Heckerman et al., 1995; Jensen, 1996; Pearl, 2011), have been applied with a risk assessment perspective to many different environmental issues (e.g. Integrated Water Resource Management, ecology, maritime spatial planning, fishery, agronomy) (Castelletti and Soncini Sessa, 2007; Barton et al., 2008; Borsuk et al., 2004, 2003; Bromley et al., 2005; Farmani et al., 2009; Gudimov et al., 2012; Henriksen et al., 2007; Lecklin et al., 2011; Renken and Mumby, 2009; Stelzenmüller et al., 2010; Zorrilla et al., 2010; Little et al., 2004).

However, the application of BNs in the context of climate change still represent a limited explored field if compare with others where their use has exponential growth during recent years. Only very few studies which explicitly apply BNs to assess and manage climate change impacts on natural resources (i.e. water scarcity and deterioration, soil erosion, biodiversity loss, eutrophication, sea-level rise) can be found in literature (Catenacci and Giupponi, 2013; Dyer et al., 2011; Gutierrez et al., 2011; Kotta et al., 2010; Molina et al., 2013; Tighe et al., 2007).

The purpose of the present work is, therefore, to discuss the application of BNs to improve climate change risks assessment and management.

The paper wants to explore to what extent BNs can be useful to enhance environmental risk assessment, through the analysis of multi-stressors issues in several case studies mainly related to natural hazards, sustainable resources management and pollution prevention in view of climate change.

Finally, it describes the use of BNs for the environmental management of climate change impacts, providing some insights of their functionalities for risks prioritization, uncertainty communication and to support practitioners in the selection of optimal adaptation measures at the regional and local scale.

To do so, a systematic analysis of existing literature is presented in Section 1. In Section 2, main advantages and limitations of BNs are discussed according to each steps of the general framework of multi-risk assessment and management (Fig. 1) thus providing a sort of “road map” for the integration of BNs also in climate change risk assessment and management procedures.

2. Reviewing Bayesian Networks applications

According to the aim of the present work, a set of case studies dealing with BNs applications in the field of environmental modelling and management were selected and analyzed.

To facilitate a comparative analysis and discussion, case studies have been categorized according to specific features (i.e. model