Environmental Modelling & Software 82 (2016) 7–20

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Methods for translating narrative scenarios into quantitative assessments of land use change

Varun Rao Mallampalli [a], Georgia Mavrommati [b], Jonathan Thompson [c], Matthew Duveneck [c], Spencer Meyer [d], Arika Ligmann-Zielinska [e], Caroline Gottschalk Druschke [f], Kristen Hychka [f], Melissa A. Kenney [g], Kasper Kok [h], Mark E. Borsuk [a, *]

[a] Thayer School of Engineering, Dartmouth College, Hanover, NH, USA
[b] Environmental Studies Program, Dartmouth College, Hanover, NH, USA
[c] Harvard Forest, Harvard University, Petersham, MA, USA
[d] Yale School of Forestry and Management, New Haven, CT, USA
[e] Department of Geography and Environmental Science and Policy Program, Michigan State University, East Lansing, MI, USA
[f] Department of Natural Resources Science, University of Rhode Island, Kingston, RI, USA
[g] Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, USA
[h] Environmental Sciences, Wageningen University and Research Centre, Wageningen, Netherlands

ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form
23 March 2016
Accepted 11 April 2016

Keywords:
Socio-ecological scenarios
Participatory process
Agent-based model
Fuzzy cognitive map
Bayesian network
System dynamics

ABSTRACT

In the land use and land cover (LULC) literature, narrative scenarios are qualitative descriptions of plausible futures associated with a combination of socio-economic, policy, technological, and climate changes. LULC models are then often used to translate these narrative descriptions into quantitative characterizations of possible future societal and ecological impacts and conditions. To respect the intent of the underlying scenario descriptions, this process of translation needs to be thoughtful, transparent, and reproducible. This paper evaluates the current state of the art in scenario translation methods and outlines their relative advantages and disadvantages, as well as the respective roles of stakeholders and subject matter experts. We summarize our findings in the form of a decision matrix that can assist land use planners, scientists, and modelers in choosing a translation method appropriate to their situation.

1. Introduction

Anticipating environmental impacts associated with future land use is an important challenge within regional global change science. However, because land use is a product of complex socio-ecological factors, accurately predicting the drivers of land-use change, let alone future land-use patterns, is typically impossible. Therefore, analyses of future land use often take a scenario approach, wherein several potential pathways are examined without an attempt to make precise or probabilistic predictions; rather, a range of possibilities are considered. In this sense, scenarios are "coherent and plausible stories, told in words and numbers, about the possible co-evolutionary pathways of combined human and environmental systems" (Swart et al., 2004). The creation and analysis of land-use scenarios allows practitioners to integrate diverse modes of knowledge and to explicitly recognize those components of complex systems that are uncertain (Thompson et al., 2012). Consequently, land use scenarios are a ubiquitous component of integrated environmental assessments at global (Alcamo, 2009), regional (Sleeter et al., 2012), and local (Carpenter et al., 2015) scales.

Scenarios take many forms and vary widely in terms of how they are developed. One useful distinction is between qualitative and quantitative scenarios (Alcamo, 2009). Qualitative land-use scenarios are non-numerical descriptions of the way the future may unfold depicted as narrative texts or storylines. Done well, qualitative scenarios offer a compelling vision that showcases the myriad consequences and interdependencies of alternative land-

* Corresponding author.
E-mail address: mark.borsuk@dartmouth.edu (M.E. Borsuk).

http://dx.doi.org/10.1016/j.envsoft.2016.04.011
1364-8152/

use decisions. Developing qualitative scenarios can be useful for generating ideas and strategies and for incorporating multiple viewpoints without requiring specific technical expertise. As such, the process of constructing scenarios can bridge gaps between and among experts, decision-makers, and stakeholders (Welp et al., 2006). Participatory scenario development is increasingly used to ensure that a range of viewpoints and expertise is captured by qualitative storylines and to maximize the legitimacy and salience of the research for decision makers (Cash et al., 2002; Seppelt et al., 2011).

Quantitative land-use scenarios, in contrast, describe plausible futures using numerical descriptions of one or more of the rates, types, and spatial allocations of land uses associated with a potential pathway. Quantitative scenarios are typically designed to support numerical assessment of specific impacts. In many cases, quantitative scenarios are derived using spatially explicit simulation models of land use and land-cover change, often coupled to models of ecosystems, hydrology, or other affected components of the environment. Accordingly, the information required for the quantitative scenario is often specific and technical, thus confining the process to scientific experts. This runs the risk of excluding non-technical viewpoints and can decrease the accessibility of results to non-experts (Voinov and Bousquet, 2010).

Often the value of scenario planning can be maximized when the inclusivity and creativity of qualitative scenarios is coupled with the specificity of quantitative modeling. Indeed, coupled qualitative and quantitative scenarios are the basis of many prominent scenario assessments in domains not directly related to land use assessment, such as the IPCC Special Report on Emission Scenarios (Nakicenovic and Swart, 2000) and the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2003). To date, the story and simulation (SAS) approach has been most commonly used to couple qualitative and quantitative scenarios. In this approach, scenarios are first defined by experts and/or stakeholders and subsequently translated into quantitative parameters that feed into simulation models (Alcamo et al., 2008; Houet et al., 2016). As shown in Fig. 1, this may be an iterative process such that narrative scenarios are translated into quantitative models that are then used to revise or enrich storylines based on the particular simulation results.

Ultimately, any modeling approach used requires a “translation” step to relate qualitative narrative scenarios to specific simulation model formulations and input values. This translation needs to adhere to the assumptions and interactions contained in the narrative, while also being compatible with the level of complexity of the chosen model (Kok, 2009). In this paper, we review the state-of-the-art of methods used to perform such translation for future land-use scenarios. Our effort was initiated as part of a recent workshop organized by the Scenarios, Services, and Society Research Coordination Network (S^3 RCN; s3rcn.org) funded by the U.S. National Science Foundation. Based on a review of the land use and land change (LULC) scenario literature, we outline the relative advantages and disadvantages of the various translations methods. Many of these methods can also be used in the original construction of the narrative scenario and/or in the model-based scenario quantification. Finally, we provide a decision matrix summarizing our findings that can assist land use planners, scientists, and modelers in choosing a translation method appropriate to their situation.

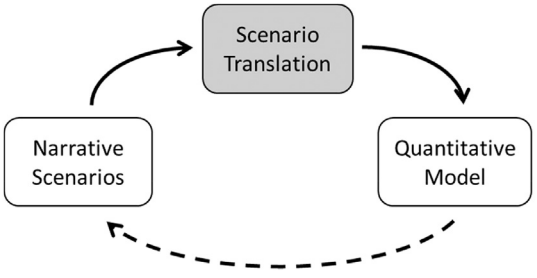

Fig. 1. Scenario development process. Dashed arrow indicates that scenario development can be an iterative process. The present paper addresses mainly the narrative translation step (gray box).

2. Translation methods

We review ten methods that can be used to translate between narrative scenario descriptions and quantitative simulation models. We evaluate each method according to the underlying conceptual foundation, treatment of uncertainty, potential to accommodate stakeholder participation, relative level of resources required, and compatibility with common simulation models. Table 1 provides a summary, including references to example applications. We also evaluate the relative advantages and disadvantages of each method in particular applications. These criteria are further elaborated in the discussion section and are summarized in the form of a decision matrix (Table 2). The purpose of this matrix is to assist scenario developers and modelers in the choice of an appropriate translation method for their particular situation.

2.1. System dynamics

2.1.1. Use in translation

System dynamics (SD) is a method for framing and disentangling the non-linear behavior of complex systems over time (Schmitt Olabisi et al., 2010). SD acknowledges that mental models are typically unable to capture features of complex systems such as feedback loops, time delays and policy resistance (Sterman, 2012). SD uses graphical causal loop diagrams (Ford, 1999) to represent cause and effect relationships and feedbacks. When used to represent human-environment interactions, the SD method has the potential to engage stakeholders in the process of understanding dynamics and defining scenarios (Mavrommati et al., 2014; Schmitt Olabisi et al., 2010; Yu et al., 2011).

The SD approach can be used for qualitative-to-quantitative scenario translation either directly or indirectly. In the direct method, researchers and stakeholders work together to understand the system under study by: (i) identifying relationships among the system's key components and leverage points and then (ii) jointly exploring plausible scenarios. This SAS-type approach typically first yields an initial causal loop diagram corresponding to a business-as-usual scenario, which corresponds to a future scenario if no changes are made to the system. This process can then be used to generate additional scenarios by exploring relevant modifications (Mavrommati et al., 2014).

In the indirect method, the scenario development process precedes the development of a causal loop diagram. For example, the Minnesota 2050 project (Schmitt Olabisi, Kapuscinski et al., 2010) used scenario visioning and stakeholder participatory modeling to develop narrative scenarios describing cause-effect relationships. Researchers then used these qualitative scenarios to identify the system variables, linkages, and underlying assumptions necessary to create a causal loop diagram (Fig. 2). Stakeholders then had the opportunity to provide their comments on the diagram at a follow up meeting. Numerical implementation of a causal loop diagram requires conversion to a stock-flow model along with additional parameterization. In the case of the Minnesota 2050 project, empirical data were used to parameterize the model with a range of values employed to explore various scenarios.