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METHODS

Evaluating strategies for sustainable development: fuzzy logic reasoning and sensitivity analysis☆

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Abstract

Sustainable decision-making involves political decisions at the local, regional, or national levels, which aim at a balanced development of socio–environmental systems. A fundamental question in sustainable decision-making is that of defining and measuring sustainable development. Many methods have been proposed to assess sustainability. Recently, a model has been developed, called Sustainability Assessment by Fuzzy Evaluation (SAFE), which uses fuzzy logic reasoning and basic indicators of environmental integrity, economic efficiency, and social welfare, and derives measures of human (HUMS), ecological (ECOS), and overall sustainability (OSUS). In this article, we perform sensitivity analysis of the SAFE model to identify the most important factors contributing to sustainable development. About 80 different indicators are tested and classified as promoting, impeding, or having no effect on the progress toward sustainable development. The proposed method is applied to the Greek and American economies. The conclusion is that there is no unique sustainable path and, accordingly, policy makers should choose different criteria and strategies to make efficient sustainable decisions for each country.

Keywords: Sustainable development; Decision-making; Indicators of sustainability; Fuzzy logic

1. Introduction

Sustainable development is nowadays the goal, in words at least, of most politicians and decision makers. Since the publication of the Brundtland report in 1987 [World Commission on Environment and Development (WCED), 1987], the concept of sustainability has gained increasing attention among policy makers and scientists which culminated during the 1992 Earth Summit held in Rio de Janeiro. Among the results of the Earth Summit, Agenda 21 is a comprehensive list of actions needed to achieve sustainable development [United Nations Conference on Environment and Development (UNCED), 1992]. Leaders from over 150 states committed themselves to undertaking actions which will render future development sustainable but without the scientific tools to guide policy making towards a sustainable path (HMSO, 1994). Decisions leading to sustainable development ought to be based on good science and adequate information. Thus, data are needed about environmen-

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tal, social, and economical factors known as indicators of sustainability. Sustainable projects and optimal strategies for development necessitate answering four fundamental questions: ''why unsustainable development occurs'', ''what is sustainability?'', ''how can it be measured?'', and ''which factors affect it?'' (Atkinson et al., 1999).

There is evidence that development is currently unsustainable. Ozone depletion, global warming, depletion of aquifers, species extinction, collapse of fisheries, soil erosion, and air pollution are among the obvious signs of ecological distress (Brown et al., 2000). Our society is also showing similar signs due to poverty, illiteracy, AIDS, social and political unrest, and violence (International Union for the Conservation of Nature/United Nations Environment Program/WorldWide Fund for Nature (IUCN/UNEP/WWF), 1991; United Nations Environment Programme (UNEP), 1992).

Recently, fuzzy logic has been proposed as a systematic tool for the assessment of sustainability. Fuzzy logic is capable of representing uncertain data, emulating skilled humans, and handling vague situations where traditional mathematics is ineffective. Based on this approach, we have developed a model called Sustainability Assessment by Fuzzy Evaluation (SAFE), which uses basic indicators of environmental integrity, economic efficiency, and social welfare as inputs, and employs fuzzy logic reasoning to provide sustainability measures on the local, regional, or national levels (Phillis and Andriantiatsaholiniaina, 2001).

This paper provides an approach to sustainable decision-making on the national level using sensitivity analysis of the SAFE model. Sensitivity analysis reveals the most important factors contributing to a sustainable society. The proposed method is applied to a number of selected economies. It becomes clear that there is no unique sustainable path and, accordingly, policy makers should choose different criteria and strategies to make efficient sustainable decisions for each country.

It should be stressed that the present work expands on our previous paper (Phillis and Andriantiatsaholiniaina, 2001). The main contribution of this research, aside from refining several points of our past paper, is the introduction of derivatives (gradients) of linguistic variables with respect to indicators. This is a nontrivial task and a necessary step towards using the full decision-making potential of the model. There are indicators whose values are good but they tend towards deterioration. The sensitivity analysis spots such indicators and often provides counterintuitive results necessary to form the full picture of sustainability.

Another point worth mentioning is that, although we provide a lot of explanation about our model, it is bound to remain a ''black box'' to some extent for the layman. To understand the model fully, one has to be reasonably versed in fuzzy logic and calculus. The software, however, can be used by the layman without difficulty. Knowledge of the inner workings of the model is required if one needs to change the knowledge bases or the membership functions. Our model, however, does not differ in this respect from most others. It is usable by the majority of interested agents but fully understood by the experts.

2. Overview of the SAFE model

2.1. Indicators of sustainable development

Sustainable development, as described by the Brundtland report, is ''development that meets the needs of the present without compromising the ability of future generations to meet their own needs'' (WCED, 1987). Although sustainable development is difficult to define using mathematical terms, many researchers recognize that it is a function of two major components, ecological and human (Pearce and Turner, 1990; Milon and Shogren, 1995; Rauch, 1998). Therefore, sustainable decision-making should have two simultaneous goals:

- achievement of human development to secure high standards of living;
- protection and improvement of the environment now and for the generations to come.

Since the Earth Summit in 1992, an increasing number of researchers and international organizations began to consider ''social sustainability'', ''economic sustainability'', ''community sustainability'', and even ''cultural sustainability'' as parts of the human dimension of sustainable development (Hardoy et al., 1992;