Decision Support Systems for Sustainable Development

A Resource Book of Methods and Applications

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and
Kluwer Academic Publishers

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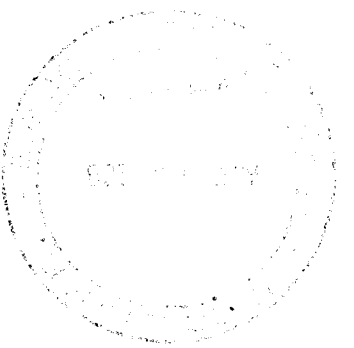

Kluwer Academic Publishers
Boston/Dordrecht/London

Library of Congress Cataloging-in-Publication Data

A C.I.P. Catalogue record for this book is available from the Library of Congress.

Canadian Cataloguing in Publication Data

Main entry under title :
Decision support for sustainable development : a resource book of methods and applications

Includes bibliographical references.
ISBN 0-88936-906-2

1. Sustainable development — Developing countries.
2. Decision making — Developing countries.
3. Information, storage and retrieval systems — Sustainable development.
I. Kersten, Gregory E.
II. Mikolajuk, Zbigniew.
III. Yeh, Anthony G.O., 1952- .
IV. International Development Research Centre (Canada).

HC79.E5D43 1999 338.9'009172'4 C99-980239-9

Published in hardcover by
Kluwer Academic Publishers
101 Philip Drive, Assimippi Park, Norwell, MA 02061, USA
http://www.wkap.nl

Printed on acid-free paper in the United States of America.

For
Margaret Kersten,
Anna Mikolajuk and
Brenda Yeh
with thanks for
their inspiration
and encouragement.
Thank you!

Contents

DECISION SUPPORT SYSTEMS FOR SUSTAINABLE DEVELOPMENT

An overview

Tung X. Bui

The chapters in this book are written out of a common interest in leveraging information technology to support sustainable development. This interest is of special importance as advanced information technology is being unleashed around the globe, transforming the way organizations – private, public or non-governmental alike – plan, implement and control business in a world tightly connected both economically and environmentally.

The use of computer-based decision support systems for sustainable development is however a complex and delicate endeavor. It involves multiple issues embracing economics, ecology, politics, and others (Glatwin *et al.* 1995). Given the very broad nature of decision support technology, the authors of the chapters in this book do not approach their work on the basis of a common methodology or a shared framework to problem solving. Instead, they are interested in suggesting a variety of ways to use decision support technology in the politics of sustainable development.

1. Sustainable development: A decision-making perspective

Sustainable development means different things to different people. Recognizing that reality, it is important to acknowledge that policies to promote sustainable development require more than just wishful thinking and rhetoric discourse. Rather than submerging in definitional diversity and abstract conception, we postulate in this book that sustainable development is a desire for a better world or future. In operational terms, this desire could be interpreted as a goal to satisfy the needs of the present generation without compromising those of future generations. Even more practically, decisions involved in sustainable development include efforts to:

- maximize resource use and energy efficient,
- reduce environmental impacts,
- avoid/improve social impacts,

- promote the use of renewable and green technologies, and
- enforce democratic decision processes through integrative bargaining.

Sustaining development is driven by multiple and conflicting goals and constraints, complex interdependencies among stakeholders and dictated by considerable moral and ethical considerations. Thus, any sustainable development effort could, and probably should, take a unique approach to deal with this complexity by dealing with predictable and unpredictable, near and far outcomes.

If one adopts our Management Science/Operations Research view of sustainable development (SD), lessons learned from modern management and the practice of decision support technology suggest a number of guiding principles for an effective approach to policy making:

- Make SD a part of mainstream thinking and strategic policy and include SD goals and objectives in the strategic plan of all involved parties,
- Establish all-level leadership to champion SD causes and justify decision rationale,
- Consider SD as a business problem and use sound economic principles to clearly define decision issues, capture all opportunities and constraints, search for team consensus and find optimal solutions,
- Leverage decisions with information technology; and
- Treat implementation of SD decisions as a major endeavor requiring careful project management.

As such, the goals and policies of sustainable development appear to be reasonably well defined and prescriptive in nature. They would lend themselves well for decision support technology.

2. Decision support technology and sustainable development

The development and implementation of decision support systems (DSS) require knowledge and understanding of managerial decision making, levels of reasoning and problem solving and roles of managers in organizations (McNurlin and Sprague 1998).

These prerequisites for using computerized decision support already constitute a challenge for those contemplating the use of information technology for sustainable development. The mandate for a better future is uncontestable but formulating this mandate in a tractable manner is non-trivial. This justifies the use of any support methodology – computerized or not – to help authorities involved in sustainable development sort out all the decision variables and parameters, problem solving heuristics, and appreciate the impacts of potential policy actions.

The process of developing a DSS often revolves around five building blocks:

1. *Information resource management.* In software engineering terms, input data are required for decision analysis and resolution; output data are generated and pre-

sented to decision makers for policy making. Effective management of these data constitutes a first major task of any decision support tool.

2. *Model management.* A model is an abstraction of reality whose purpose is to help decision makers focus on the main elements of a problem. Multiple objective optimization under constraints is a classic modeling approach in management science. Qualitative reasoning, expert heuristics, and data mining are alternative methods to formulate decisions. Given a decision problem, the challenge of DSS is to find the best decision method(s) able to suggest a satisfying solution to policy makers.

3. *Interactive problem solving.* Direct interaction between the DSS and its user allows for a more responsive and user-centered view of the problem. A good DSS is one that provides the right information to the right person at the right time with full transparency. In addition, DSS should provide some cognitive feedback to decision makers by helping them comprehend dynamic changes in the underlying assumptions.

4. *Communications and teamwork support.* Decision making, more often than not, involves more than one decision maker and support for communication and coordination is an important dimension of DSS. Support for information exchange, federated organizational memory, group decision and negotiation is an integral component of organizational decision support.

5. *DSS as non-human co-workers.* In a tightly connected networked world, we postulate a working scenario in which humans will team up with computers as co-workers to optimize execution of business decisions (Negroponte 1995). We envision a new social structure that emerges from the interaction of individuals—both humans and non-humans — operating in a goal-oriented environment under rules that place only bounded demands on each individual's information and computational capacity (Bui 1999). In the multi-dimensional context of sustainable development, various DSS, such as those reported in this book, could serve as task-specific aids to policy makers.

The immediate value of using these five building blocks is to help the DSS users improve their decision outcomes. DSS should achieve its support mission by lending a hand to its users: More quality input data are expected to provide a more complete assessment of the problem situation and a richer set of decision alternatives. More sophisticated decision algorithms are expected to help decision makers find solutions that could not have been found otherwise. Expansive real-time trade-off analyses and interactive simulation are expected to provide decision makers with further insights. Communications and group decision support are expected to increase the chance of finding a shared vision and socially equitable solution. Finally, computerized coordinated DSS workflow should seamlessly enhance the integration of sustainable development at a national or global scale.

Perhaps, a more far-reaching value of using DSS is its ability to improve the way decision makers approach the problem, i.e., new insights into the business, better decisions and faster responses to unexpected situations, and most importantly, a changing consciousness about environmental responsibility. Altogether, DSS should help its

users become better informed workers in dealing with their information-intensive sustain-centrist tasks.

A unique feature of this book is a balanced mix of concepts, techniques and case studies to substantiate the framework outlined herewith.

3. Book organization: Scopes, contributions and issues

The book is organized in four parts. All in all, they offer a mix of topics including fundamental concepts of decision support, applications and some directions for further research.

In the first chapter, Yeh and Mikolajuk unequivocally remind the readers that sustainable development is rather an evasive, multi-faceted concept. It is not surprising however if one realizes the breadth and depth of sustainable development activities, ranging from long-term economic growth to short-term preservation of resources, from basic research of resource conservation and replenishment to potentially controversial policy making.

As such, defining decision making tasks, and finding ways to support them, require a comprehensive classification of problem types, information requirements, decision making procedures, selection of decision makers involved in the process and, last but not least, the spatial and temporal impacts of sustainable development decisions. Yeh and Mikolajuk provide some examples how information technology – and particularly, that of decision support tools – can help facilitate these elaborate tasks. Implicit in their analysis is the need of identifying the types of decisions in sustainable development and selecting appropriate decision support tools for these decisions.

Kersten provides a comprehensive review of decision making – both from individual and organization perspectives. He proposes a framework bridging basic levels of individuals' cognitive articulation to Herbert Simon's classic organization decision making model (Simon 1960). This framework serves as a foundation for establishing DSS requirements from a systems development standpoint. The requirements for decision support are presented in the context of the key aspects of problem solving and decision making.

Yeh (Chapter 3) exemplifies the contribution of decision support technology in the formulation and implementation of actual sustainable regional development strategy with the use of Geographic Information Systems (GIS). GIS allows use of digital technology to store and retrieve massively large geographic data bases for interactive modeling, simulation and forecasting of urban, regional or environmental plans. Despite the increasing number of successful applications of GIS, Yeh quickly shares the viewpoint of management information systems (MIS) researchers in cautioning the reader that the success or failure of sustainable development depends more on political and managerial leadership than on advanced technology.

The concept papers, when taken together, are expected to enhance the reader's ability to understand the instances in which decision support systems can be deployed. They argue that information technology can help improve decision quality by putting

into place computer systems that help gather relevant information, build context-dependent data and knowledge bases and interactive human-computer interaction.

The nine chapters in Part 2 deal with specific cases of the use of management science and decision support technology in dealing with a variety of sustainable development situations.

Modern management science and advanced information technology have been the two main driving disciplines of this book to support decision making in sustainable development. A unique feature of the DSS applications in this book is the explicit effort of modelers to integrate economic efficiency with social constraints and productivity with ecology. As pointed out repeatedly by the contributing authors, a number of requisites are necessary – i.e., sustaincentrism leadership, innovative approach to modeling sustainable development, and better information resource management, if these two disciplines are to support ecologically and socially sustainable development.

The following five factors should be considered when designing DSS for sustainable development:

1. *Decision makers*: Sustainability is a participatory process of creating and fostering a shared vision that commands prudent use of natural and human resources. Decision makers should be solicited beyond the reliance of public authorities. All stakeholders should democratically and pro-actively assume their decision-making responsibilities in taking charge of their fate and that of future generations – in spite of a decision environment prone to faulty assumptions and lacking of incentives for personal integrity.

2. *Decisions*: Sustainable development must be driven by a commitment to ensuring a life-sustaining earth. As such, decision making in sustainable development should embrace all economic, social, political and environmental components to maximize productivity while assuring the long-term viability of natural systems on which all life depends.

3. *DSS Modeling approach*: Modeling sustainable development requires an exhaustive search and gathering of economic and ecological information, comprehensive goal formulation and constraints, and context-dependent knowledge and heuristics for problem solving. Modeling sustainable development implies management of interdependencies between multiple and conflicting goals, a search for solutions that are equitable to current and future generations, and assessment of potential and chronic threats and protection from counterproductive disruption. Full cost accounting of environmental impacts, multiple objective optimization, simulation and forecasting methods and applied artificial intelligence techniques are possible techniques that can be used for sustainable development.

4. *Database requirements.* Quality data are required for successfully putting modeling into practice. Research in database design often cautions the difficulty in setting up data for DSS. Data needed for DSS are typically historical data with extrapolation potential. The data are typically retrieved and combined from multiple sources, characterized by a varying degree of detail and accuracy. Conventional database management systems are not designed to handle these types of requirements effectively. It is the obligation of the SD researchers not to neglect the challenge of putting into place an information management plan for sustainable development.

5. *Visualization and interface requirements:* Decision algorithms should be transparent to policy makers. The conventional wisdom in human-computer interaction feature – what-you-see-is-what-you-get – is an example of how interface design can promote this transparency. Interface controls should be designed to allow DSS users to "navigate" the problem at hand through time (e.g., past experience, current impacts, and future consequences), space (e.g., local, national, and global implications), problem determinants (e.g., decision variables versus constraints, flows versus stocks), and perspectives (e.g., partial versus holistic scope). (Bui and Loebbecke 1996)

Table 1 provides a synoptic view of these case studies along the dimensions described above; with the exception of the visualization and interface requirements as most systems adopt standard graphical user interface technology.

The chapters in Part 2 demonstrate rather conclusively that sustainable development is indeed a tractable problem when formulated appropriately, and such a formulation attempt is more likely to benefit than confuse the policy makers.

Another remark can be made here. Most if not all of the countries covered in the chapters are developing countries. Implementing DSS in developing countries required the followings to be taken into consideration:

- *"Pay-the-price-later" attitude:* Due to the urgent needs of the present, decision authorities are constantly under pressure of having to neglect the future.
- *Relative political and administrative instability:* The political climate in developing countries has been typically unstable, making institutional commitment rather uncertain.
- *Insufficient infrastructure:* Inadequate infrastructure, compounded with inferior technology, tends to hinder information technology innovation and use. This includes the lack of data, resources, leadership and technical competencies.

Interestingly and oftentimes, sustainable development applications are not treated at a global or national level. Instead, they deal with specific projects of economic development at a regional level, such as such as water quality planning for a specific regional river, rural energy development for a village, and land management of a cooperative. The regional scope of the applications suggests that economic solutions devised for, and lessons learned from, a region could be used to inspire solutions for another region having a similar sustainable development problem situation.

The four chapters of Part 3 explore new research attempts to support sustainable development. Again, adopting a building block approach, these chapters focus on recent trends in information technology in the decision support field. In Chapter 13, Ho proposes a rule induction process that seeks to automatically derive knowledge from raw data. Ho's contribution is an example of the current effort by information scientists to deal with information overload, i.e., attempting to discover interesting but non-obvious patterns of information hidden in large and heterogeneous data sets.

Burstein *et al.* (Chapter 14) look at supporting the process of exploring decision alternatives by providing decision makers with some historical knowledge about the decision context. They advocate the implementation of an organizational memory system to provide an information environment conducive to effective organizational

No.	Author(s)	Country	Sustainable development area	Decision to be supported	Decision maker(s)	DSS modeling approach	Database requirements
4	Yeh and Li	China	Land resource management	Search for equitable use of land resource between generations; identify spatial efficiency in land use	Planners and government officials	Remote sensing and GIS modeling to monitor present and future supply and demand of land resources	Physical properties of land; demographic and economic data
5	Gamboa	Philippines	Water supply planning and investment	Water planning; Search for optimal investment in water supply facilities	Local geo-political units: provincial and national governments, funding agencies	Object modeling and knowledge-based systems	Water demand and supply data; funding data
6	Gailly and Installe	Burundi	Rural Development: land increase and intensification of commercial exchanges	Define incentive strategies: technical assistance to farmers and creation of non-agricultural jobs	Public authorities	Multiple criteria optimization; Impact analysis	Agricultural and economic data including weather and export data
7	Lotov, Bourmistrova and Bushenkov	Russia	Water quality planning in large rivers	Efficient strategies in water planning	All stakeholders involved in water quality planning	Feasible Goals Method and Interactive Decision Maps	Environmental data

No.	Author(s)	Country	Sustainable development area	Decision to be supported	Decision maker(s)	DSS modeling approach	Database requirements
8	Pokharel and Chandra-shekar	Nepal	Rural energy planning	Minimize government energy cost; maximize rural employment; maximize energy use efficiency	Planning authorities	Multi-objective programming methods and geographic information system	Energy data
9	Rais, Gameda, Sajjapongse and Bechstedt	South-East Asia	Land management to support sustainability	Identify the sustainability of the land	Planning authorities	Knowledge-based Inference	Qualitative and quantitative data elicited from local experts
10	Costa and Ensslin	Brazil	Textile industry	Sustain industry survivability with tradeoff analysis	Industry experts and owner-managers of textile firms	Cognitive mapping of critical success factors	Socio-economic data
11	Mohan, Kersten, Noronha, Kersten and Cray	N/A	Train decision authorities for sustainable development	Decision and negotiation in technology transfer, cooperation and trade	Planning authorities	Economic model of negotiation with maximization of joint outcomes	Case study data
12	Raefa	Egypt	Information transfer on crop management and water and soil conservation	Site assessment, seedling production, cultivation, agriculture practice management, disorder diagnosis and remediation	Land-use officials, researchers and farmers	Knowledge-based systems	Expert knowledge bases

decision making. They join Ho's work by noting the potential of knowledge management techniques. The latter could be embedded in their proposed framework to help decision experts collapse large amounts of data into "aggregated" trends, correlating patterns cross-sectionally or over time, and uncovering decision knowledge.

In Chapter 15, Hall attempts to elevate the design of DSS to an international level. He proposes a DSS architecture that supports multiple national languages. An innovative aspect of his work is to go beyond simple interface translation. Rather, Hall advocates the design of a culture-dependent human-computer interaction approach that takes into consideration linguistic user interface and cultural factors (e.g., use of currency, use of color display, legal requirements, etc.). Such a system architecture would be an essential first step if the decision making process for sustainable development is to reach the global level.

Hall sets the stage for Chabanyuk and Obvintsev (Chapter 16) to explore the possibility of using state-of-the-art software technology to design complex multi-layered environmental decision and management processes. Setting aside their technical discussion, the authors try to demonstrate that integration of large-scale environmental management could be done via computer system integration.

In Chapter 17, Abel *et al.* use their experience in the design of a DSS to integrate hydrological models, databases and spatial information systems for water quality management in Australia to suggest an approach to linking various exogenous DSS building blocks together. Using a connector/facilitator concept they argue that a federated software architecture would enhance scalability of the DSS as it evolves over time.

Mahadevan *et al.* close Part 3 with a more detailed discussion of the use of data mining and knowledge discovery methods for building DSS (Chapter 18). These new enabling technologies give the old management adage – information is power – a heightened dimension.

As intended, the chapters in Part 3 venture into the frontiers of technology. The issue one would have to raise is how much technology is sufficient – a threshold of engineering complexity beyond which technology could become a burden rather than an aid to policy makers.

It is rather a challenging task to close an edited volume rich in scope and diversity. To a large extent, the two chapters in Part 4 live up to this challenge. In Chapter 19, Hall *et al.*'s chapter incarnates a considerable and collective view of how, and under what conditions, decision support technology can be an integral part of sustainable development. The critical success factor here is the integral aspect of DSS deployment. This is not just about technology. This is about developing the right technology for the right decision problem to be implemented in the right decision environment.

To close the volume, Kersten and Lo (Chapter 20) provide the readers with a classified set of DSS examples. With a twenty-year or so history of using computer technology for decision support, the list they present is only a subset of the significant achievement researchers from the fields of Management Science, Operations Research, Computer Science and Information Systems. Surely, the list of references provided should be seen as an assurance that DSS can deliver. Better yet, it should be viewed as a source of inspiration for researchers and practitioners seeking to creatively exploit information technology for sustainable development.

4. A resource book for a pro-active approach to sustainable development

The chapters in this book embody the important progress made in decision support technology as it applies to sustainable development. As such, they put us in a far better position to track and analyze decisions related to sustainable development. This in turn should improve our ability to help prescribe policy measures, and thereby the attainment of the ultimate challenge of sustainable development.

Each piece of research in this edited book was conducted without reference to the work of others. Nor were the authors asked to have their chapter be integrated in the general framework of using information technology to support sustainable development. This remark is by no means a weakness of the book. On the contrary, the maturation of DSS technology has resulted in a multitude of highly specialized, problem-focused and mission-critical methodologies and applications. All together, they constitute a concerted and pro-active approach to sustainable development. This book should be seen as a unique set of methods and tools that could be deployed in the context of sustainability.

When dealing with large-scale problems involving multiple constituencies, many people find complexity dull. They argue that simple decision making principles and rules are easier to remember and to apply. They also justify that dramatic arguments can be used to convey these principles to the stakeholders of a decision related to sustainable development. This book is an effort to go beyond an account of generic policy formulation to an analytical and computer-supported platform for effective management and policy making. By doing so, it is expected that the impact of decision making in sustainable development tends to be much more profound than one might anticipate, and the use of decision support technology could be instrumental and long lasting. From this standpoint, this book is an invaluable resource of methods and applications for those who wish to exercise their responsibilities for a better world or future.

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