

# Decision Support Systems for Sustainable Development

A Resource Book of  
Methods and Applications

EDITED BY  
GREGORY E. KERSTEN  
ZBIGNIEW MIKOLAJUK  
ANTHONY GAR-ON YEH

International Development Research Centre (IDRC)  
and  
Kluwer Academic Publishers

# **DECISION SUPPORT SYSTEMS FOR SUSTAINABLE DEVELOPMENT**

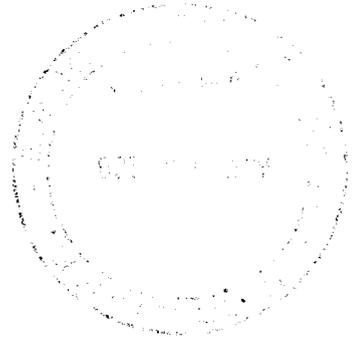
*A Resource Book of Methods and  
Applications*

# DECISION SUPPORT SYSTEMS FOR SUSTAINABLE DEVELOPMENT

*A Resource Book of Methods and  
Applications*

**Gregory (Grzegorz) E. Kersten  
Zbigniew Mikolajuk  
Anthony Gar-On Yeh**

*Editors*



**Kluwer Academic Publishers  
Boston/Dordrecht/London**

ARCHIV  
MIKOLA  
no. 113698

---

## 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

---

© International Development Research Centre 2000

PO Box 8500, Ottawa, Ontario, Canada K1G 3H9

<http://www.idrc.ca/books/>

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, mechanical, photocopying, recording, or otherwise, without prior permission from Kluwer Academic Publishers, 101 Philip Drive, Assinippi Park, Norwell, MA 02061, USA.

*Published in hardcover by*

Kluwer Academic Publishers

101 Philip Drive, Assinippi 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

|  |     |
|--|-----|
| <b>Preface</b>   | xi  |
| <b>Decision Support Systems for Sustainable Development : An Overview</b><br>Tung X. Bui   | 1   |
| <b>I. SUSTAINABLE DEVELOPMENT AND DECISION MAKING</b>  |     |
| <b>1. Sustainable Development and Decision Support Systems</b><br>Zbigniew Mikolajuk and Anthony Gar-On Yeh  | 13  |
| <b>2. Decision Making and Decision Support</b><br>Gregory E. Kersten   | 29  |
| <b>3. Decision Support with Geographic Information Systems</b><br>Anthony Gar-On Yeh   | 53  |
| <b>II. APPLICATIONS AND CASE STUDIES</b>   |     |
| <b>4. Decision Support for Sustainable Land Development:<br/>A Case Study of Dongguan</b><br>Anthony Gar-On Yeh and Xia Li                           | 73  |
| <b>5. Water Resource Management: A Case Study for EcoKnowMICS</b><br>Eduardo D. Gamboa   | 99  |
| <b>6. Decision Support for Incentive Strategies:<br/>A Rural Development Application in Central Africa</b><br>Benoit Gailly and Michel Installé      | 131 |
| <b>7. Efficient Strategies: An Application in Water Quality Planning</b><br>Alexander V. Lotov, Liubov V. Bourmistrova, and<br>Vladimir A. Bushenkov | 145 |
| <b>8. Integrated Rural Energy Decision Support Systems</b><br>Shaligram Pokharel and Muthu Chandrashekar   | 167 |

|   |     |
|---|-----|
| <b>9. DSS for Sustainable Land Management:<br/>A South-East Asia Case</b>   | 183 |
| Mohammad Rais, Samuel Gamede, Eric T. Craswell,<br>Adisak Sajjapongse, and Hans-Dieter Bechstedt                  |     |
| <b>10. Mapping Critical Factors for the Survival of Firms:<br/>A Case Study in the Brazilian Textile Industry</b> | 197 |
| Carlos A. Bana e Costa, Émerson C. Corrêa, Leonardo Ensslin<br>and Jean-Claude Vansnick                           |     |
| <b>11. Learning Negotiations with Web-based Systems:<br/>The Base of IIMB</b>                                     | 215 |
| T. R. Madanmohan, Gregory E. Kersten, Sunil J. Noronha,<br>Margaret Kersten and David Cray                        |     |
| <b>12. Natural Resource Conservation and Crop Management<br/>Expert Systems</b>                                   | 239 |
| Ahmed Rafea   |     |
| <b>III. RESEARCH ISSUES</b>   |     |
| <b>13. Rule Induction in Constructing Knowledge-Based<br/>Decision Support</b>                                    | 263 |
| Tu Bao Ho   |     |
| <b>14. Organizational Memory Information Systems<br/>A Case-based Approach to Decision Support</b>                | 277 |
| Helen G. Smith, Frada V. Burstein, Ramita Sharma<br>and Dayo Sowunmi  |     |
| <b>15. Software Internationalization Architectures for DSS</b>  | 291 |
| Patrick A.V. Hall   |     |
| <b>16. Software Integration for Environmental Management</b>  | 305 |
| Victor S. Chabanyuk and Olexandr V. Obvintsev   |     |
| <b>17. Design of Decision Support Systems as<br/>Federated Information Systems</b>                                | 329 |
| David J. Abel, Kerry Taylor, Gavin Walker and Graham Williams   |     |
| <b>18. Knowledge Discovery in Databases and Decision Support</b>  | 343 |
| Anantha Mahadevan, Kumudini Ponnudurai, Gregory E. Kersten<br>and Roland Thomas                                   |     |

**IV. DECISION SUPPORT SYSTEMS FOR SUSTAINABLE DEVELOPMENT**

**19. Experience and Potential**

369

Patrick A.V. Hall et al.

**20. DSS Application Areas**

391

Gregory E. Kersten and Gordon Lo

**Glossary**

409

**Contributors**

415

# 1 SUSTAINABLE DEVELOPMENT AND DECISION SUPPORT SYSTEMS

Zbigniew Mikolajuk and  
Anthony Gar-On Yeh

## 1. Introduction

In this book, we focus on one aspect of the many processes leading to sustainable development – support for decision-making. A vision for sustainable development implies a long-term process, in which decisions on economic, ecological, and community development are based on the best available information and coordinated at the local, regional, and global levels.

Any discussion on technical support for decision-making in different domains should consider a holistic approach to human problem-solving, the concrete environments in which decision support systems (DSSs) will be used, and the acceptance of the system by the user. The ultimate goal is a system under which international organizations, governments, local authorities, and individuals are able to conduct negotiations as well as coordinate and evaluate their own independent decisions.

A discussion on a global system is beyond the scope of this book, which describes decision support technologies and selected applications. The implementation or even the design of a global system to protect our planet is perhaps beyond our present abilities. However, well-defined components like river basin management or health care support systems can and should be both designed and implemented. Such initial modules then can be further developed, integrated, and refined in the future.

## 2. The concept of sustainable development

No single term or definition can define the concept of sustainable development precisely. There are many operational definitions. The concept is not new: it can be traced back 2 000 years to the time of the ancient Greeks. The idea of sustainability probably appeared first in the Greek vision of 'Ge' or 'Gaia', the goddess of the Earth, the mother figure of natural replenishment (O'Riordan, 1993). Under her guidance,

Greeks practised a system of sustainability under which local governors were rewarded or punished according to whether the fields looked well-tended or neglected. Later, concern about the limited productivity of land and natural resources can be seen in Malthus' essay on population in 1789 and Ricardo's *Principles of Political Economy and Taxation* in 1817. Their concern was that economic growth might be constrained by population growth and limited available resources.

Toward the end of the 19<sup>th</sup> and the beginning of the 20<sup>th</sup> century, the prosperity of the Western economy created an optimistic view of the future. Natural resources were no longer seen as posing severe restrictions on economic growth, as new technologies made far more efficient use of both old and new resources. The fragility of this economic growth was revealed, however, by the world oil crisis and economic recession of the 1970s. Neo-Malthusians began to have doubts about unlimited growth, stressing once again the importance of conserving natural resources by setting limits to economic growth.

In April 1968, the Club of Rome gathered to discuss the present and future predicament of the Earth and its finite resources. The results of its deliberations were published in *The Limits to Growth* (Meadows *et al.*, 1972). The book predicted that the limits of growth on Earth would be reached sometime within the next 100 years if the economy continued to expand at the current rate. The sorry state of our finite resources was the result of exponential growth in global population, resource depletion, and industrial pollution. In 1992, 20 years after this controversial book was published, the same authors published its successor, *Beyond the Limits*, which re-examined the situation of the Earth (Meadows *et al.*, 1992).

With new evidence from global data, the book shows that the exponential growth in the global population, economy, resource consumption, and pollution emissions continues unabated. In 1971, they had concluded that the physical limits to human use of materials and energy would be reached within decades. In 1991, after re-running the computer model with newly compiled data and analyzing the latest development pattern, they realized that in spite of improved sustainable development policies throughout the world, the world might well be approaching its limits even faster than they had thought.

Another sustainability concept can be found in the 1960s notion of carrying capacity in resource management. This concept can be described in wildlife management as "the maximum number of animals of a given species and quality that can, in a given ecosystem, survive the least favourable conditions within a stated time period"; in fisheries management as "the maximum biomass of fish that various water bodies can support"; and in recreation management as "the maximum number of people that a recreational site can support without diminishing the recreational experience that attracted people to it in the first place" (Edwards and Fowle, 1955; Dasmann, 1964; DHUD, 1978).

The most recent concept of sustainable development is a modified derivative of the concepts of growth limits and carrying capacity. It not only stresses the importance of resources in setting limits to economic growth but also draws attention to the need to develop methods that emphasize the potential complementarity between economic development and environmental improvement (Markandya and Richardson, 1992).

In the Brundtland report, sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations

to meet their own needs" (Brundtland, 1987). It is also considered to be "a process of social and economic betterment that satisfies the needs and values of all interest groups, while maintaining future options and conserving natural resources and diversity" (IUCN, 1980).

Sustainable development does not mean no development. It means improving methods for resource management in an environment where there is an increasing demand for resources (Levinsohn and Brown, 1991). Sustainable development represents a new synthesis of economic development and environmental protection. Economic activities inevitably are associated with the consumption of natural resources. As populations increase and the pace of economic development quickens, there is a widespread concern about the scarcity of natural resources.

Modern technologies, however, which are improving much faster than ever before, can help alleviate the environmental impacts of economic development. Social and political configurations also can alter the development pattern for achieving long-term economic growth that can be sustained by the environment. Policies can be designed to modify the behaviour of development by regulating its activities. Planning, environmental management, performance standards, fines, taxes, and licences are other economic instruments for controlling development and internalizing its costs.

Important milestones in discussions on sustainable development are the report *Our Common Future*, published in 1987 by the Brundtland Commission; and the document *Agenda 21*, developed for the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992. The Gaia Hypothesis (Myers, 1985), formally proposed in 1973, is closely related to concepts of sustainable development and provides very interesting philosophical and theoretical insights into planetary life as a whole.

Three vital processes affect the sustainability of development: economic development, ecological development, and community development (Figure 1). Sustainable development brings the three into balance with each other and negotiates among the interest groups and stakeholders involved in the processes. It provides a program of action for community and economic reform, such that economic development will not destroy ecosystems or community systems. There is a growing consensus that sustainable development must be achieved at the local level if it is ever to succeed on a global basis (ICLEI, 1996).

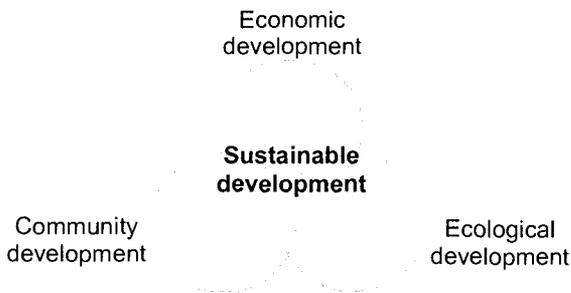


Figure 1. The three interrelated processes of sustainable development.

### 3. Operational definition of sustainable development

While sustainable development is becoming a widely acknowledged concept (Repetto, 1986; Redclift, 1987; SGSNRM, 1988), there is considerable disagreement on how to implement it. This is because there is no general operational framework for defining sustainable development.

There are more than 70 different definitions of sustainable development, each offering a number of possible modifications to the development process and different reasons for them (Steer and Wade-Gery, 1993). One of these definitions is that development for the future should be based on continuing and renewable processes and not on the exploitation and exhaustion of the principal living resource base (Loening, 1991). Population would be a key factor to be considered here. The implementation of sustainable development can be pursued only if population size and growth are in harmony with the changing productive potential of the ecosystem. The ECCO (enhancement of population carrying capacity options) computer system developed at the Centre for Human Ecology at the University of Edinburgh, is an example of a system that attempts to guide policy-making toward economic development that is more sustainable (Loening, 1991). It tries to answer the question of how we can identify the trade-offs between population growth and standard of living and between intensification of agriculture and soil conservation.

Other definitions of sustainable development focus mainly on sustaining economic development. Sustainable development can be defined as economic development that endures over the long run (Turner, 1993). Some authors, however, think that ecological considerations should be an integral part of economic development. Barbier (1987), for example, argues that sustainable development depends on interactions between three systems: the biological (and other natural resources), the economic, and the social. The goals of sustainable development for the three systems are

- maintenance of genetic diversity, resilience, and biological productivity for the biological system;
- satisfaction of basic needs (poverty reduction), equity enhancement, and increasingly useful goods and services for the economic system; and
- assurance of cultural diversity, institutional sustainability, social justice, and full participation for the social system.

There seems to be no general agreement on the concept of sustainable development. Some people put a high value on a healthy environment, while others prefer high living standards. Income, education, social structure, and ideology are factors that determine the definition of sustainable development in a community. Therefore, some rules need to be designed to guide people toward sustainable development. One such rule might be that a given renewable resource cannot be used at a rate greater than its reproductive rate. Otherwise, it will become totally depleted.

Strict controls on the use of nonrenewable resources are necessary to prevent the possibility of depletion. Substitutions and new technologies can help conserve scarce resources. Abatement measures should be taken to reduce pollution as well. The amount of pollution emissions should not exceed the assimilative capacity of the environment.

Biodiversity in the ecosystem is threatened as more and more species become extinct as a result of human activities. Many species improve the human living environment by generating soil, regulating fresh water supplies, decomposing waste, and cleaning oceans. New genes of great value are being discovered by researchers in many fields. It is thus crucial to maintain a healthy biodiversity by controlling ecosystem balance.

Sustainable development is something every country and every region of the world should work to achieve. Countries differ, however, in their perceptions of sustainable development. There is great difficulty, therefore, in designing universal measurements and indicators of sustainable development because countries also differ in the importance they assign to different components of sustainable development (UNCSD, 1995; Mitchell, 1996). It is here that information technology (IT) can help: IT tools like DSSs can be developed to help local governments and countries to achieve sustainable development once they define their operational indicators.

#### 4. Agenda 21

*Agenda 21*, a document developed for UNCED, is the result of a comprehensive analysis of what is needed to achieve sustainable development (UNCED, 1993). Its 40 chapters on environmental, economic, social, and organizational issues contain guidelines for developing decision-making processes. Four other key documents were completed at the Rio Conference:

- The Rio Declaration on Environment and Development (The Earth Charter);
- The Statement of Guiding Principles on Forests;
- The Convention on Climate Change; and
- The Convention on Biodiversity.

The purpose of this section on the contents of *Agenda 21* is to help select specific issues for further study on domain-specific decision support and identify the concrete information systems needed in the decision-making processes.

Sustainable development has become an important research issue for many disciplines. Since the Brundtland report, thousands of publications have contributed to a better understanding of the holistic approach to human development and the critical issues of environmental protection, use of natural resources, social development, and well-being. Almost every aspect of life on Earth is represented in this world-scale model of sustainable development.

The *Agenda 21* document presents a framework for processes and actions that will bring the world closer to the concept of sustainable development outlined there. It is based on the principles and recommendations of the Brundtland report and other contributions submitted during the preparatory process by government and nongovernment organizations.

Since the 1992 Rio Conference, much attention has been focused on the political issues of *Agenda 21*, on setting priorities, and on the disagreements surrounding UNCED. At the same time, the implementation of many practical, widely-accepted objectives still remain a subject of scientific discussions and strategic plans. The lack

of progress or significant practical steps toward the achievement of sustainable development since 1992 was discussed at the Rio+5 Conference in 1997.

We believe that advances in information and communication technologies in recent years have made it possible to develop practical and effective information systems which can meet the critical needs highlighted in the 40 chapters of *Agenda 21*—improved access to information and support for decision-making. In this and the next chapters we concentrate on the roles DSSs can play in achieving these objectives

*Agenda 21* is divided into four sections, each of which addresses one fundamental dimension of sustainable development:

1. social and economic;
2. conservation and management of resources for development;
3. strengthening of major groups; and
4. means of implementation.

#### 4.1. Section I

The Preamble to *Agenda 21* points out that no nation can achieve sustainable development alone. A global partnership and broad public participation are needed to solve the problems of development. It also recognizes that additional financial resources; the strengthening of public institutions; and well-conceived plans, processes, and implementation strategies will be needed.

In Chapters 2 through 8, on the social and economic dimensions of sustainable development, the authors discuss policies and measures that will have to be designed and implemented to foster trade liberalization, deal with international debts, and create trade and macroeconomic policies that both encourage development and protect the environment.

The document devotes special attention to combating poverty. Some 25% of the people in the developing countries are extremely poor. The creation of new jobs, better education, accessible primary health services, new community-based initiatives, demographic dynamics, and the rehabilitation of degraded resources are considered critical factors for poverty alleviation. *Agenda 21* recognizes that consumption patterns, particularly in developed countries, pose a real threat to the world's ecosystem, and that they must change.

Chapter 6 affirms that the primary health care needs of the world's population must be met if the objectives of sustainable development are to be met. The main issues are the health-care needs of people in rural areas, the control of communicable diseases, the protection of vulnerable groups, urban health problems, and the reduction of health risks from environmental pollution.

Chapter 7 is about the development of human settlement. The proposed program areas indicate the scope and nature of the problems. They include the need to provide shelter to all people and better management of human settlements. The document promotes good managerial practices, especially sustainable land-use planning and management, integrated provision of environmental infrastructure (water, sanitation, drainage, and solid-waste management), sustainable energy and transport systems in

human settlements, human settlement planning and management in disaster-prone areas, and sustainable construction-industry activities. Chapter 7 also promotes human resource development and capacity building for human settlements.

Chapter 8 closes the first section and calls for the improvement and fundamental reshaping of decision-making processes at all levels of government, and participation from a broader range of public in decision-making. Improvement of planning and management systems should be based on domestically determined procedures and a holistic approach to economic, social, and environmental issues. The strengthening of national capacity, the development of new methods and tools for data collection, accounting and finance, the strengthening of the legal framework, human resource development, and international cooperation are among the many program initiatives proposed in this chapter.

#### *4.2. Section II*

This section focuses on the immediate need to use and manage natural resources wisely so that future generations will be able to meet their survival needs.

Chapter 9 deals with issues related to the Convention on Climate Change. It proposes recommendations on the reduction of atmospheric emissions and the prevention of ozone layer depletion, and calls for international data sharing and research into the modeling and forecasting of atmospheric processes.

Chapters 10 through 16 propose an integrated approach to land-use planning and management. This means that economic and social factors as well as ecological, biological and geological ones are taken into account during the decision-making process. Deforestation is causing serious problems — deterioration of watersheds, soil erosion and loss of land productivity, flooding, loss of genetic diversity, and global warming. Better ways to manage forests, and concrete actions to combat deforestation are outlined in Chapter 11. Related issues of combating desertification and drought are covered in Chapter 12. Developing information systems and sharing knowledge are integral parts of the proposed programs. Knowledge-building, the promotion of management and planning methods, and capacity building at all levels are highlighted in Chapters 13 through 16 by dealing with sustainable agriculture, rural and mountain development, conservation of biological diversity and biotechnology.

Chapters 17 and 18 recognize that oceans and freshwater resources are critical elements of global life. As in the other chapters, the issues of integrated management, environmental protection, sustainable use of resources, stronger cooperation, and knowledge sharing are discussed in the context of concrete program areas.

Chapters 19 through 24 attempt to specify concrete targets and deadlines for handling toxic chemicals, hazardous wastes, solid wastes and sewage, and radioactive wastes. The proposed programs again cover a wide area: information exchange on toxic chemicals and chemical risks, capacity building, training, establishment of government policies, community programs, prevention of illegal international traffic in toxic and dangerous products, research on hazardous waste management, recycling, globally harmonized hazard classification, and compatible labeling systems for chemical materials.

### 4.3. Section III

This section deals with identifiable groups of people who can contribute to development through education and training and thereby improve their living standards: women, children, indigenous peoples, rural communities, nongovernment organizations (NGOs), local authorities, workers, the community of business and industry, the science and technology community, and farmers. One of the fundamental prerequisites for the achievement of sustainable development is broad public participation in decision-making and access to information.

### 4.4. Section IV

This section reviews the implementation of sustainable development objectives. Chapters 33 through 39 deal with financial issues; institutional, national, and international arrangements; technology transfer; the role of science; public awareness and training; capacity building; and international legal mechanisms.

Chapter 40 deals with the problem of bridging the gap between developed and developing countries in the availability, quality, coherence, standardization, and accessibility of the data needed to make informed decisions. It sets the following four objectives:

- more cost-effective and relevant data collection and assessment at all levels;
- stronger local, provincial, national, and international capacity to collect and use multisector information in decision-making processes;
- more and stronger local, provincial, national, and international means of ensuring that planning for sustainable development in all sectors is based on timely, reliable, and usable information; and
- relevant, available, and easily accessible information.

Data collection is a necessary but not sufficient condition for better decision-making, however. There is not enough recognition that the capacity building to collect, store, and disseminate information must be accompanied by a concerted effort to develop the theory and practice of DSSs. These and other knowledge-based technologies play a significant role in sustainable development by providing the tools to support the implementation of the Agenda 21 objectives. They make it possible to encode knowledge on the basis of data that are relevant to specific problems, process and aggregate data, and use information to arrive at meaningful conclusions.

## 5. Technical support for development decisions

### 5.1. Application domains

DSSs are built for a specific class of problems or a well-defined application domain. *Agenda 21* provides a broad background for the analysis of requirements, scope of development decisions, and specific cases.

A practical and critical barrier to sustainable development is how to make and coordinate a wide range of decisions on a local and global level. Technical aids are essential for both information- and judgment-driven decision-making. The interdependence of international, regional, and national development requires a greater exchange of information, sharing of knowledge, and coordination of actions than in the past. Local as well as global factors must be taken into consideration and available academic as well as traditional knowledge must be applied to solve sustainable development problems. DSSs that are well integrated with decision-making processes and valued by decision-makers will contribute to the implementation of the objectives of sustainable development.

Developing resources in a sustainable way requires a holistic approach to human development and the preservation of the natural environment. Decisions on economic, political, or social activities should target concrete problems, but at the same time be based on an analysis of all the implications derived from the paradigm of sustainable development. Many decision-makers are not prepared to handle the complexity of such an analysis. DSSs with a built-in knowledge of the analysis and the capability to investigate and correlate large amounts of data are needed.

A step-by-step approach, international collaboration, determination of priorities, development of adequate methods and technologies, and training are the key factors in this process. A whole range of collaborating DSSs for specific domains will have to be developed and institutionalized to provide effective tools for coordinated actions. Detailed analysis is needed on not only the support requirements but also on how to develop and deploy systems and what their roles are in decision-making.

Since the 1970s, DSS research has concentrated on financial (banking, insurance) and medical systems. In recent years, the following application domains for DSS technology have been investigated from the viewpoint of decision-making for sustainable development:

- land and water management;
- food production and distribution;
- poverty alleviation;
- primary health services;
- public services and administration, governance;
- education;
- pollution control;
- environmental management;
- urban planning and management;
- recovery from a natural disaster;
- population growth control; and
- economic planning.

This is an open list with interrelated and overlapping areas. Useful software applications have been developed for solving many specific problems in these domains. The application areas and references to many specific DSS models and systems are given in Chapter 21. Critical issues are the integration of information systems designed for decision support, standardization, dissemination, institutionalization, and the global networking of systems. The need for multilingual systems and communication (exchange of data and models) between different systems adds to the complexity of system implementation.

Software applications developed for decision support must take into consideration the wide variety of users and their cognitive capabilities. Information, knowledge, and decision-making for development need to be analyzed in the context of human behavior and institutional structures. The main knowledge processor is a human being, not a computer. The computer system merely helps integrate and present the academic and traditional knowledge required for decision-making.

## 5.2. *Decision support systems*

There are many definitions for DSSs and their functions in decision-making; several definitions and key functions are discussed in Chapter 2. One should note, however, that different definitions are used in a technology driven market to sell a particular technology. The perspective that we advocate and further elaborate is centered on the user and problem rather than the method and tool. Usually, a combination of different software tools is needed to develop DSSs for sustainable development applications. This is the perspective proposed in Chapter 2 (see Figure 5 in that chapter for a summary).

Policy decisions provide a context and an overall mission statement for operational and resource allocation decisions. For example, one policy decision could be the health improvement of the population in a given region of a country. Such a decision is made as a result of deliberations on government priorities and available resources. In order to achieve the policy goal, operational decisions have to be made at different administrative levels on the allocation of health services, training of medical personnel, supply of fresh water, sanitation, and so forth.

DSS development requires taking into consideration cultural and political factors in addition to technological components. A methodology for the integration of various software technologies, knowledge acquisition tools, and specific user needs is required. The methodological perspective presented in Chapter 2 provides a basis for a comprehensive treatment of decision support and DSS functionalities. Further studies undertaken by interdisciplinary teams of researchers with diverse cultural backgrounds and domain expertise also are needed to focus on the provision of culturally sensitive support methods that allow local knowledge and specific requirements to be incorporated into DSSs.

A background analysis and requirement specification of a support system for decision-making should take into consideration the following factors:

- type of decision problem (policy, operations, resource allocation, etc.);
- domain and scope of the decision problem;

- organizational and structural boundaries;
- decision-making process;
- impact on and synergy with the existing system;
- expected consequences of decision execution;
- profiles of decision-makers (users of the system);
- external constraints and contexts; and
- objectives of a DSS.

The strong interrelation between decisions taken to solve specific problems in different domains introduces additional complexity to the design and use of DSSs. A general model of decision analysis and support for a particular sustainable development domain, such as the management of fresh water resources, for example, may include the format and availability of information, traditional and academic knowledge sources, and interfaces with other systems (land management, legal, market, and others). In addition, it might be required to incorporate the processes of decision-making at those levels of administration that have direct impact on and can contribute to the solution of the problem (household/community, regional, national, and so forth).

Conventional decision-making is aimed at individual problems. Complex geographic or domain interrelationships are not considered because there is a lack of adequate tools to consider different approaches to a given problem.

Decision-making at the level of national governments or large organizations requires different support and tools from those needed for decision-making at the village or single farm level. In either case, the development of a computerized DSS makes economic sense if one or more of the following utility characteristics apply:

- a large amount of data must be collected and processed to produce and analyze decision alternatives (e.g. environmental protection);
- decision-making procedures are applied to many cases within a domain (e.g. immigration application processing) or periodically repeated (e.g. crop management);
- there are many potential users in a given domain (e.g., health services planning);
- it is critical to make top-quality decisions in a short period of time (e.g., recovery from a natural disaster);
- access to the top-level expertise required for decision-making is restricted and expensive (e.g. environmental impact assessment); and
- the possibility of a large number of alternative decisions (e.g., social services planning) with significant and different implications.

The main purpose of a DSS is to help make quality decisions. New methodologies and DSS development tools that include knowledge-based software (see Chapter 12) and knowledge discovery software (see Chapters 13 and 18) are needed to support

DSS developers at each stage of the development cycle. Local knowledge, political culture, and tradition are critical factors in the development and successful institutionalization of a DSS. These issues are discussed at greater length in Chapters 15 and 19.

### 5.3. *DSS technologies*

The computer and telecommunication technologies available today allow DSSs to meet demanding functional and user interface requirements. In this section, we deal with some technical topics on the use of specific technologies in DSS development.

A DSS in the domain of sustainable development provides access to and makes use of a variety of databases. In a broad sense, electronic text documents, statistical data, tables of numerical data, digitized maps, drawings, and images are data types processed by a DSS. Domain experts determine which data are needed in the decision-making process, which data are critical for optimal decisions and which sources of data are available.

Formal descriptions of data base structures, data modeling, and the formulation of performance requirements from the point-of-view of decision-making processes are the tasks of DSS developers. For example, a DSS for water quality protection requires all kinds of hydrological, chemical, biological, meteorological, and geographically encoded data on waste water discharge points, manufacturing plants, food processing plants, and water consumption. The DSS developer must identify the appropriate data to show the relationship between water quality and economic activities, municipal water management, and natural phenomena.

The identification of existing data sources and elaboration of procedures and methodologies for collecting data in the field are tasks for the collaborative work of domain specialists and software developers. Data modeling, remote access to data bases, conversion of data, data verification and validation, translation of textual data in a multilingual system, standardization of data formats and access methods, and integration of database management systems with a DSS are technical problems which often have very good solutions. We should consider the adaptation of these solutions in the development of a concrete DSS.

In the real world, decisions are made sometimes despite the fact that complete and accurate data are not available. Data verification modules in a DSS should have built-in knowledge for assessing the validity of the conclusions and the proposed solutions produced by the system in the case of incomplete or unreliable data.

Modeling capability is a major DSS characteristic. Forecasting and decision evaluations are based on computer models. A complex DSS requires a collection of models. Software architecture should include facilities for a model repository, the selection of appropriate models, and the composition of model subsets to solve complex problems. The selection of models in response to a specified problem is a knowledge-based process. An analysis of formal descriptions of decision problems and domain models should generate a scenario for applying a collection of models in a given situation. Take water quality protection, for example: simulation models could help to analyze an emergency situation, like the contamination of a river. A hydrological model of the river and contaminant dispersion would help to determine remedial actions.

Domain knowledge acquisition and encoding are a continuous activity in DSS design and implementation. Decision-making is based on available information and the knowledge of the decision-makers. The acquisition and encoding of that knowledge require specific tools and skills. In the case of government systems, a DSS developer deals with unstructured and distributed knowledge. Legislative documents, policy statements, office procedures and instructions, reports, and programs are sources of knowledge in addition to human expertise and experience. Extracting knowledge from textual documents and integrating it into the document repository with a DSS knowledge base requires software tools such as natural language processors, document management systems, knowledge-acquisition software, and textual information retrieval systems. The analysis of data and textual documents, manipulation of models, generation and evaluation of decision alternatives are knowledge-based procedures.

Knowledge-based software modules (for example, embedded expert systems, rule-based models, and intelligent user interfaces) are components of DSS architecture. Integration of these components and the creation of a consistent knowledge base are the most challenging tasks.

Expert system technology provides facilities for generating an explanation on how and why particular conclusions were drawn. The concept of collaborating expert systems could be useful in solving some problems in a way similar to decision-making by an interdisciplinary group of experts. Expert system technology is useful in addressing the problem of incomplete and unreliable data. A rule-based system with built-in uncertainty factors allows for the analysis of decision-making procedures and evaluation of the probability of results.

The knowledge-based approach to the development of DSSs also involves investigation of the theory and practice of self-learning systems and machine learning.

Support for making optimal decisions to solve a problem is only one step in the decision-making process; determining the consequences of implementing a selected decision is another.

The specification of indicators describing the results of executed decisions, and the collection of pertinent indicator values should constitute a component of DSSs. The domain knowledge base and models can help specify indicators and monitoring procedures. The analysis of indicator values provides feedback for the improvement of the DSS and verification of system software modules. A strict formal analysis supported by software would aid the process of practical implementation of learning algorithms and indicator design.

The design and quality of the user interface are critical if a DSS is to be accepted and used by decision-makers. The complexity of the software and data management has to be understandable to the user, who should be able to concentrate on the decision problem and not be distracted by computer operation-related activities. There are three types of users with different requirements for the interface — developers, domain experts, and decision-makers. The analysis of user profiles and specific domain requirements should encompass the following characteristics and design issues:

- the interactive formulation of a decision problem (structured seminatural language communication between the user and the system),
- the use of graphic tools and images to describe problems,
- case-based dialogue in problem formulation,

- the interactive manipulation of models by means of domain-specific natural language communication,
- the presentation of data in a visual format (GISs, elements of multimedia, and graphics),
- the presentation of decision-making rules and explanation facilities,
- knowledge-based support for user interface features and run-time control (context-sensitive help functions), and
- the ability to adjust to both novice and experienced users.

From the user's point of view, the basic requirements are easy-to-use (intuitive) dialogue facilities and comprehensible responses from the system. A DSS must be attractive to users who do not have the time or willingness to learn computer operations and formal command languages.

The development of DSSs requires the integration of various selected software development tools and methodologies. This should result in specifications for a domain-specific software architecture (DSSA) suitable for development and delivery of a DSS in a particular application domain. Existing system development software, including tools such as DSSA (Tracz, 1995) should be analyzed from the perspective of DSS development. Existing application software modules are building blocks for DSS implementation.

The chapters in this book show how DSSs can be used in the economic, ecological, and social systems as well as development processes of sustainable development. Many of the systems are at the preliminary stage of development. There is a need to identify and further develop DSSs that are useful to the planning and management of sustainable development. No matter how sophisticated and advanced it is, a DSS is useless if it is not being used by decision-makers.

There is a need to persuade government officials and decision-makers to use DSSs in their work. They have to be provided with training so that they can understand and use the technology. Some real-world demonstration projects would be helpful to demonstrate the usefulness of DSSs in the sustainable development field. At the start, such projects do not need to be very sophisticated, but the systems they produce must be operational. Decision-makers should be able to make their own modifications to the parameters and techniques of the DSS to suit the needs of their local communities.

## References

- Barbier, E.B. (1987). "The Concept Of Sustainable Economic Development", *Environmental Conservation* 14(2), 101-110.
- Brundtland (1987). *Our Common Future*, World Commission on Environment and Development, Oxford: Oxford University Press.
- Dasmann, R. F. (1964). *Wildlife Management*. New York: Wiley.
- De la Court T. (1990). *Beyond Brundtland - Green Development in the 1990s*, New York: New Horizon Press.

- DHUD (1978). *Carrying Capacity Action Research: A Case Study in Selective Growth Management*. U.S. Department of Housing and Urban Development, Oahu, Hawaii, Final Report.
- Edwards, R. Y. and C.D. Fowle (1955). *Transactions of the 20th North American Wildlife Conference*. Washington, D.C.: Wildlife Management Institute.
- ICLEI (1996). *The Local Agenda 21 Planning Guide: An Introduction to Sustainable Development Planning*, Toronto: International Council for Local Environmental Initiatives.
- IUCN (1980). *World Conservation Strategy*. Gland, Switzerland: International Union for the Conservation of Nature, Gland, Switzerland, 2.
- Levinsohn, A.G. and S. J. Brown (1991). "GIS and Sustainable Development in Natural Resource Management", in Heit, M. and M. Shortreid, (Eds.), *GIS Applications in Natural Resources*, GIS World, Inc. 17-21.
- Loening, U.E. (1991). "Introductory Comments: the Challenge for the Future", in A.J. Gilbert and L.C. Braat, (Eds.) *Modelling for Population and Sustainable Development*, London: Routledge, 11-17.
- Markandya, A. and J. Richardson (1992). "The Economics of the Environment: An Introduction", in Markandya, A. and Richardson, J. (Eds.), *Environmental Economics*, London: Earthscan, 7-25
- Meadows, D.H., D. L. Meadows. and J. Randers (1992). *Beyond the Limits*, London: Earthscan.
- Meadows, D.H., D. L. Meadows et al. (1972). *The Limits to Growth*, New York: Universe Books.
- Mitchell, G., (1996). "Problems and Fundamentals of Sustainable Development Indicators", *Sustainable Development* 4(1), 1-11.
- Myers, N. (Ed.) (1985). *The Gaia Atlas of Planet Management*, London: Gaia Books Ltd.
- O'Riordan, T. (1993). "The Politics of Sustainability", in Turner, R.K. (ed.), *Sustainable Environmental Economics and Management: Principles and Practice*, New York: Belhaven Press, 37-69
- Redclift, M. (1987). *Sustainable Development: Exploring the Contradictions*, London: Methuen.
- Repetto, R. (1986). *World Enough and Time*, New Haven: Yale University Press.
- Steer, A. and W. Wade-Gery (1993). "Sustainable Development: Theory and Practice for A Sustainable Future", *Sustainable Development* 1(3), 23-35.
- SGSNRM (1988). *Perspectives of Sustainable Development*, Stockholm Group for Studies on Natural Resource Management, Stockholm.
- Tracz W. (1995). "DSSA (Domain-Specific Software Architecture) Pedagogical Example", *Software Engineering Notes* 20(3).
- Turner, R.K. (1993). "Sustainability: Principles and Practice", in R.K. Turner (ed.), *Sustainable Environmental Economics and Management: Principles and Practice*, New York: Belhaven Press, 3-36.
- UNCED (1993). *Agenda 21: The United Nations Programme of Action from Rio*, United Nations Conference on Environment and Development, New York, United Nations.
- UNCSD (1995). *Indicators of Sustainable Development: Framework of Methodologies*, United Nations Commission on Sustainable Development, New York: United Nations.