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1997

document version
Early version, also known as pre-print

citation for published version (APA)
Nijkamp, P. (1997). *Environmental security and sustainability in natural resource management. A decision support framework*. (Research Memorandum; No. 1997-63). Faculty of Economics and Business Administration.

Faculteit der Economische Wetenschappen en Econometrie

Serie Research Memoranda

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Research Memorandum 1997-63

December 1997

vrije Universiteit *amsterdam*

ENVIRONMENTAL SECURITY AND SUSTAINABILITY IN NATURAL RESOURCE MANAGEMENT:

A DECISION SUPPORT FRAMEWORK

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pn698.7.97

Abstract

This paper seeks to offer an overview in recent issues in sustainable development and environmental security policy, as far as resource management is concerned. The focus is on agricultural policy analysis, with a particular view on the development of an operational decision support system. Three topics receive particular attention: the use of relevant indicators, the development of a set of critical threshold conditions, and the design of an assessment and evaluation methodology.

1. Recent Issues in the Sustainability and Security Debate

The interest in environmental issues dates back to ancient civilisation (e.g., Greek philosophy made a coherent sub-division into four elementary substances: earth, air, fire and water). The interest has remained over the centuries, with the exception that in the past decades the awareness has grown that problems of environmental sustainability and security are interwoven phenomena ranging from local to global dimensions (see also Benedick 1992). In this context, various thematic issues involved in global environmental change are distinguished, such as: land use and land cover change, industrial transformation and energy use, demographic and social dimensions of resource use, social and individual choice mechanisms, institutions, and environmental security. A main question in all such issues is whether our society has the capability and resilience to adjust itself to stress factors of a socio-political or environmental nature. Furthermore, it is also important to appreciate that adequate scientific knowledge on the nature, backgrounds and directions of environmental change processes should become available to a world-wide audience in order to induce the necessary behavioural and political adjustments (see also Lonergan 1996, and Opschoor 1996).

In the present paper we will focus on various methodological aspects of environmental sustainability and security, with a particular view on land use and agricultural activities. Particular attention will be given to new evaluation methodologies, based on recently developed decision support methods using critical threshold values via the so-called flag model.

2. Agriculture: A Natural Resource Sector in a Multi-polar Force Field

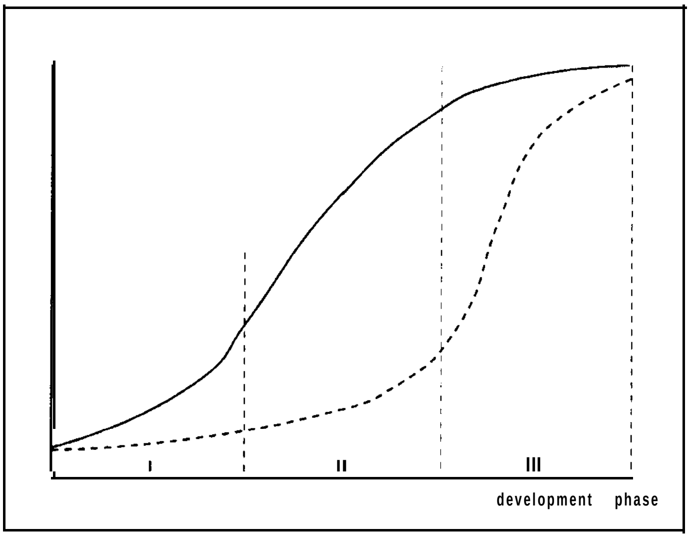
Agriculture is a natural resource sector of preponderant importance. It plays a pivotal economic role in many developing countries and is crucial for any development policy. In this context, the World Conference on Agrarian Reform and Rural Development (WCARRD) (1988) claimed that the primary objective of rural development is the eradication of poverty, anger and malnutrition, which can be further specified by means of the following development objectives:

☐ reduce rural poverty,
☐ eliminate severe under-nutrition,
☐ provide minimum levels of public services,
☐ expand employment opportunities,
☐ improve productivity and incomes,
☐ increase agriculture and food production,
☐ increase self-reliance,
☐ achieve food security, and
☐ increase public resources management.

This long list comprises a variety of relevant policy angles which may be (partly) naturally conflicting. A more compact set of objectives was adopted at FAO's preparatory meeting in 's-Hertogenbosch (The Netherlands) (1991) for the United Nations Conference on Environment and Development (UNCED),

where three goals for agricultural policy and rural development were formulated:
☐ to attain food security;
☐ to generate employment and income in rural areas and to eradicate poverty;
☐ to conserve natural resources and protect the environment.

Clearly, such goals will normally have different policy weights in different circumstances related to the development stage of an area. This is illustratively sketched in the next figure (see Figure 1).



_____ economic objective
-—— environmental objective

Figure 1. Objectives and development

In this figure the economic objectives start from achieving food security (I), move then to reducing poverty in rural areas (II), and end with providing a minimum level of public services (III). The environmental objective refers in the first phase to the maintenance of the quantity and quality of natural resources (I), next to an improvement of natural resources management (II) and finally to the maintenance of environmental quality (III). Clearly, in both economic and environmental objectives we may face issues of (in)equity and access to resources, which may have to be included as well in such a scheme.

It is clear from the above observations that economic development and management of natural resources find a concentration point in the agricultural sector (including fishery and forestry) which plays a key role in both developing and developed economies. Agriculture is thus a strategic economic sector in almost all countries, while it is at the same time a threat to our natural environment. Thus, agriculture has to find a balanced position in the complex force field of **economic objectives, social needs** and **environmental protection,** so that complicated trade-offs will be faced.

The strategic position of agriculture rests on the fact that this sector serves to satisfy basic human needs, while especially in developing countries a large share of employment is generated by this sector. At the same time, agriculture is concerned with the use of natural resources whose functioning is critical for ecological systems quality. Overexploitation of such resources erodes not only the ecological base, but also the economic prerequisites for our life support systems. This means that agriculture plays an absolutely critical role in a co-evolutionary development strategy of each country.

Clearly, new technologies may help to improve the efficiency in agricultural production, but may at the same time be harmful because of overexploitation of resources and less environmental-benign production modes. Thus a fine tuning between economic progress, technical skills and environmental management is necessary for a balanced development of agriculture in all countries, while it ought to be recognized that specific countries or regions may need tailor-made agricultural development strategies. In general, it seems to be an important objective to involve the local population as much as possible in the development process, to avoid large welfare gaps in the same agricultural area and to seek for a maximum degree of self-sufficiency of agricultural areas. Thus, the compliance with efficiency and equity targets suggests that a food security level be achieved whenever possible by indigenous growth efforts rather than by foreign aid policies. In agreement with the words of Ogutu (1992), we might thus say that *“development is for the people, from the people and with the people ″*. Nevertheless, in practice there is a wide diversity of choices to be made which may find a balance between threats and opportunities regarding resource management and land use management in the agricultural sector.

3. Sustainable Development and Environmental Security in Agriculture

The rising popularity of the notion of **sustainable development** has increasingly provoked the need for an **operational** (i.e., practical, measurable and policy-relevant) description or definition of this concept. The standard, widely-cited WCED definition of sustainable development as *“a development that fulfils the needs of the present generation without endangering the future needs of future generations”* is a meaningful starting point, but fails to offer manageable practical guidelines for sustainability strategies of (local, regional, national or international) decision-making bodies or other actors. The complementary description of sustainable development by the IUCN/UNEP/WWF emphasises from a more ecological angle the need for *“improving the quality of human life while living within the carrying capacity of supporting ecosystems”*. This definition is clearly more normative in nature and offers a test framework for resource policy, once a concensus on the carrying capacity has been achieved. Although thus far no uniformly accepted definition has emerged, the basic intentions of the sustainability concept are becoming increasingly clear: it aims at directing decisions of policy bodies and private actors towards a joint state of the economy (or society at large) and the ecology, such that the needs of current and future generations are fulfilled without eroding the ecological basis for a proper welfare and activity level of these generations (see also Opschoor 1994).

A **normative** orientation of sustainability requires in general an assessment and evaluation framework which should be able to test actual and future states (or developments) of the economy and the ecology against a set of reference values. This approach, also adopted in the present paper, requires three important components in any sustainability analysis:

☐ a set of **measurable sustainability indicators** (see Section 4)
☐ a set of **normative reference values** (e.g., carrying capacity) (see Section 5)
☐ a **structured impact and evaluation methodology** for assessing future developments (as a result of behavioural processes, exogenous developments or policy responses) (see Section 6).

Although these three items seem evident, it ought to be recognized that a major problem in operationalizing the notion of sustainable development is its **lack of specificity** in concrete circumstances (e.g., particular regions or economic sectors). A sustainable development in a given region or sector is not necessarily sustainable elsewhere. Thus, apart from the intrinsic dynamics in the interpretation of sustainability (as a process with ongoing tradeoffs between social, economic and environmental goals), sustainability is **context-specific** and hence co-determined by needs and opportunities in a particular region or sector. This awareness has in the meantime led to a more flexible delineation of sustainable development by referring to **regional or sectoral sustainable development,** witness popular notions like 'the sustainable city', 'sustainable transport', 'sustainable tourism' or 'sustainable agriculture'.

In the ongoing discussion of sustainable development, also FAO has developed its own definition by encapsulating the interest of agricultural activities. Sustainable development is in the practical FAO description to be conceived of as *"environmentally non-degrading, technical appropriate, economic viable and socially acceptable"*. Later on, this broad notion was put in a more precise context by specifying the features of a sustainable development as follows: *"Resource use and environmental management are combined with increased and sustained production, secure livelihoods, food security, equity, social stability, and people's participation in the development process"*. This means clearly that in the FAO view this notion refers to a balance between environmental, social and economic objectives to obtain maximum welfare (broad definition) while taking account of external factors (such as technology). Thus, this definition regards sustainability as a balanced state in a force field of three distinct motives, each with its own indigenous value. It has to be added that agriculture comprises various heterogeneous sub-sectors (such as cattle breeding, food production, forestry, fishery etc.) each of which may require its own specific operational definition within the above reference definition.

From a more normative policy perspective, it seems plausible to extend the above FAO definition by describing sustainable development (in a given subsector of agricultural activity and in a given region) more precisely as: **a balanced development policy for agricultural resources in the region concerned, to**

such an extent that a maximum level of welfare (including quality of life) - now and in the future - is achieved through a co-evolutionary strategy in which environmental constraints emerging from the regional carrying capacity or critical loads are taken into consideration.

As mentioned above, in addition to sustainable development also the concept of environmental security has in recent years become an important signpost for a cohesive and balanced socio-economic-environmental policy, not only at a global level, but (increasingly) also at a meso (regional or sectoral) level.

It seems plausible to adopt also a normative interpretation of environmental security. This concept is related to the access to natural resources to the extent that basic human needs can be fulfilled. In a negative sense, environmental security may be seen as absence of malnutrition, of starvation, of illness due to lack of medical care of adequate housing, or of safe living conditions (e.g., in flood areas). In a positive normative context we might define **environmental security** as a socio-economic state of an area that is employing its natural environment base and its natural resource to such an extent that all members of society have the opportunity to meet their basic needs.

The introduction of normative conditions (limits, standards, norms) on resource use and access is in agreement with popular notions like carrying capacity, maximum yield, critical loads, environmental utilization space, maximum environmental capacity use, and so forth. The use of reference values, critical conditions or threshold values is likely an appropriate way of generating new and practical insights among users (planners, experts, policy-makers) regarding the identification of conflicts, inconsistencies or incompatibilities between different agricultural development scenarios (in terms of both types and levels of agricultural activities, as well as of their underlying life support systems) .

Clearly, this requires an identification of various **classes of relevant indicators,** which may in general relate to:

- ☐ impacts on ecosystems
- ☐ impacts on water quality and quantity
- ☐ effects on climate change and atmosphere
- ☐ use of (renewable and non-renewable) resources
- ☐ generation and disposal of waste
- ☐ changes in land use and landscape
- Cl visual intrusion
- ☐ impacts on human health.

Such a set of classes of indicators is of course not exhaustive; the ultimate choice of relevant indicators depends on the general agricultural field area under investigation (e.g., livestock, forestry, fishery etc.) and on the specific policy issues and strategies to be envisaged (e.g., new cultivation methods, use of herbicides or pesticides, change in land ownership, changes in animal husbandry, changes in the natural resource base, new nota systems for fishery etc.).

By assessing all relevant effects, a data base can be created which may serve to judge whether a certain agricultural development is sustainable or not, whether policies have been more of less successful, and whether new initiatives support sustainable development or environmental security. This implies in all cases the use of an impact assessment (either ex post or ex ante), which means that the status quo (the initial conditions), the extent and type of intervention (e.g., policy), and the resulting new state have to be assessed and evaluated.

4. Indicators for Sustainable Development and Environmental Security

In general, an indicator is a partial, representative and quantitative mapping of a compound phenomenon into a one-dimensional measure which is relevant for decision-making. Single indicators, or sets of indicators, serve to assist analysts in preparing balanced policy decisions, based on the principle of communicability of data via a systematic representation of measurable facts or aspects. Such indicators have to fulfil normally the following conditions:

☐ scientific basis (i.e., verifiability)
❑ measurability (quantitative or qualitative)
☐ predictability (under ‘what-if’ conditions)
• I user- and policy-relevance
☐ flexible space-time aggregation scale
☐ monitoring capability (in a flexible information system)
☐ compatibility with available information bases.

Only under such conditions may we expect indicators to represent a high quality and reliability, a high policy relevance and a sufficient user manageability .

A first step towards an operationalization of the **latent** concepts of ‘sustainable development’ and ‘environmental security’ is to specify a set of **manifest or observable/measurable indicators** each of them depicting an important aspect of sustainability or security. Such indicators should measure all relevant dimensions of sustainable development and environmental security by including environmental, social and economic characteristics.

In order to assess the level of economic welfare, we usually look at GNP per capita. This is a macro-economic tool which measures production and economic growth in an aggregate and quantitative way. In principle, this measure can be further subdivided into regional or sectoral measures (including the social distribution of GNP). But average GNP per se does not seem to be particularly helpful in measuring sustainable development or security. In this respect, the Human Development Index (HDI), advocated by UNDP (1990), seems to offer more opportunities as an alternative indicator for development, as it incorporates both social and economic indicators. This approach is based on the assumption that human development is the process of enlarging people’s choices, where the most basic rights are concerned with healthy life, education and a decent standard of living. Nevertheless, it is still difficult to include also many environmental aspects in a measurable way, as for social and environmental values such composite indicators are more difficult to define.

In a natural resource and agricultural context, indicators may relate to different **stages of the production chain** and related environmental effects. We may distinguish between:

- ☐ **input** indicators (e.g., pesticides, fertilizers, labour, land)
- ☐ **output** indicators (e.g., production, income, pollution emission)
- ☐ **impact** indicators (e. g ., efficiency, health, ambient concentration, nutrition levels)

Such indicators may concern economic, social and environmental aspects of agriculture. These indicators can also be subdivided into efficiency-oriented and equity-oriented indicators. Sometimes the economic and social aspects are brought together in a single socio-economic profile. In all cases policy-relevant sustainability indicators are concerned with both **socio-economic** and **environmental** aspects of agricultural development. Examples of elements of a **socio-economic profile** in the agricultural sector are:

- ☐ income per capita
- ☐ skewness of income distribution
- ☐ unemployment level
- ☐ access to natural resources
- ☐ average duration of unemployment
- ☐ investments
- ☐ growth in production
- ☐ access to and use of technological knowledge and equipment
- ☐ training and educational level
- ☐ demographic structure and growth
- ☐ cultural inertia. and so forth.

Examples of **environmental** indicators (interpreted in a broad sense) are:

- ☐ water quality
- ☐ health condition
- ☐ quality of and access to health care systems
- ☐ longevity
- ☐ infant mortality
- ☐ food supply
- ☐ nutrition level
- ☐ air pollution
- ☐ soil pollution
- ☐ noise
- ☐ landscape deterioration
- ☐ general natural resource condition
- ☐ top soil quality
- ☐ pollution abatement technologies
- ☐ distribution of pollution over various social classes or regions, and so forth.

The above lists of indicators are only indicative and have to be operationalized for specific policy questions and geographical areas. A main problem is of course that the number of indicators always tends to grow towards unmanageable size. A general useful methodology for limiting the number of indicators, while nevertheless maintaining completeness and cohesion, is to use a **hierarchical** approach, based on a tree-like composition for aggregation and disaggregation of indicators, so that a distinction between single and composite indicators can be made (see Figure 2). Such a tree-like structure can of course also be further distinguished according to relevant time scales (e.g., medium-and long-term) and geographical scales (e.g., district or country).

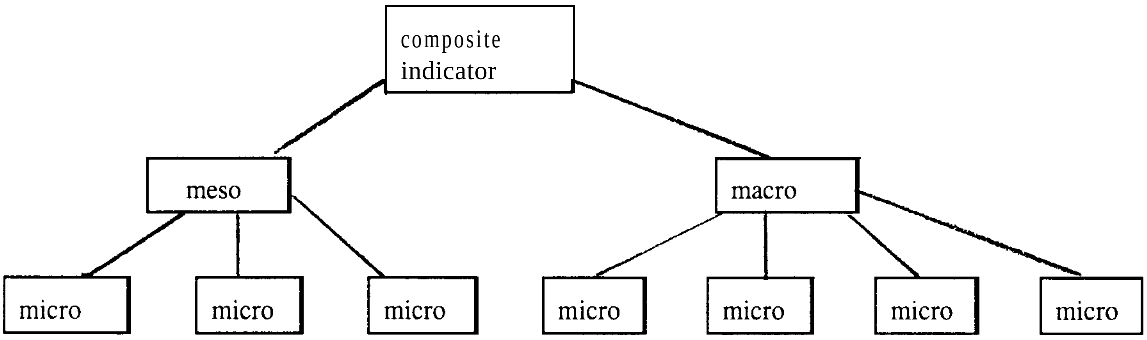


Figure 2. A tree structure for indicators based on hierachical aggregation

We will now discuss environmental security indicators. It is clear that the identification and definition of such indicators do not only depend on the area of agricultural policy concern (e.g., crop production, livestock, forestry), on the intensity of socio-economic problems, or on the extent of environmental deterioration, but also on the distribution of and access to resources among various groups in the region, and on the level and stage of development in the area concerned (see also Figure 1).

An example may illustrate the latter point. If in a **first** development stage the main policy concern on resources is to achieve **food security,** then it is evident that - in addition to income per capita, its growth and its distribution - a sufficient food supply, a stable growth path of food production over time, and a broad social access to food supply are main requirements for environmental security.

The International Fund for Agriculture Development (IFAD) (1992) has developed a composite food security index in order to measure the quantity and quality of food supply. This index includes inter alia the food production potential, the import capacity of the area concerned and the degree of variability in food production and consumption. The index is composed as follows:

- ☐ per capita daily calorie supply (as a percentage of requirements);
- ☐ per capita food production index;
- ☐ food staples self-sufficiency ratio;
- ☐ food aid in cereals (as a percentage of cereals imports)
- ☐ food imports (as a percentage of total merchandise imports);
- ☐ variability of production of food staples;

☐ variability of consumption staples.

Another attempt to typify and assess food security has been made by UNDP (1992), where various indicators were listed but not integrated in one compound index. These indicators were:

☐ food production per capita;
☐ agricultural production (as percentage of GDP);
☐ daily calorie supply per capita;
☐ daily calorie supply (as percentage of requirements);
☐ food import dependency ratio;
☐ cereal imports;
☐ food aid in cereals (as a percentage of cereal imports);
☐ total value of food aid.

A problem economists would face with such indicators is that they are partly based on supply conditions and partly on demand conditions. This means that essentially a combined supply-demand analysis might be more appropriate, as sketched below in Figure 3. In reality, however, it appears to be very difficult to assess all indicators in an equilibrium point so that in practice one has to resort to a mixed indicator system.

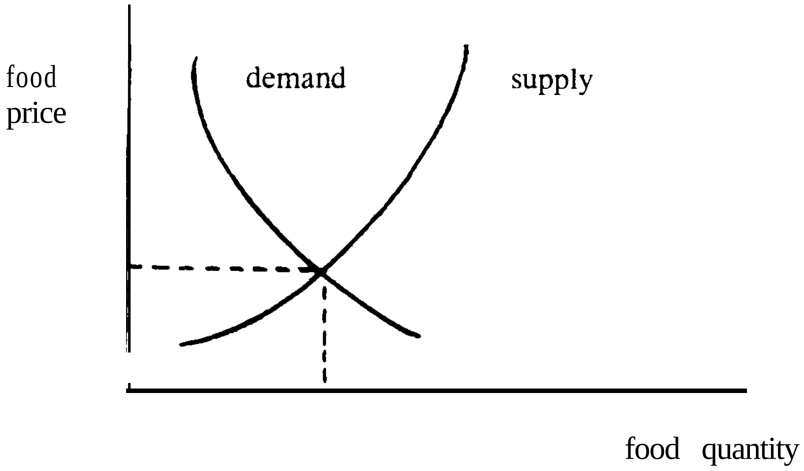


Figure 3. Demand and supply curves for food

It is clear that distributional problems are at the heart of environmental security. Since a direct equity index is difficult to identify, one normally resorts to indirect indicators, such as the percentage of people under the standard nutrition level or infant mortality (percentage of infants dying in their first year of life). It is evident that such health indicators are also strongly related to income distribution.

Next, if we would face a **second** development phase (see Figure 1), e.g. a case of poverty in rural areas, then other indicators might be relevant. In this case, indicators related to basic standards of living or basic necessities may be used. For instance, an attempt has been made by the World Bank (1990) to assess poverty by introducing poverty lines as a critical threshold value. This line appears to vary from $270 to $370 in the 1990 Global Assessment on Poverty. Thus in this case, indicators do not refer to survival conditions, but to basic standards of living. Related indicators may be the unemployment rate or food aid dependency.

Finally, if a **third** development stage (see also Figure 1) would be faced with much emphasis on national resources conservation and environmental protection (including public services such as health care, educational facilities and other welfare benefits), conventional indicators such as income per capita and public expenditures per capita - and the distribution thereof - are obviously more appropriate security indicators.

Having discussed now concisely the phase dependency of sustainability and security indicators, we will next address a few critical indicators which seem to play an important role in almost all development situations. Agriculture should not be regarded in isolation from the natural resources **water** and **soil quality,** as these two categories offer the basic life support systems now and in the future. If we take for granted that *"sustainable development implies that the environmental impact of human activities stay well within limits of how much environmental impact the biosphere can take"* (RMNO 1994), then we have to recognize that at any given point in time there are limits to the amount of environmental pressure that the earth's ecosystem can support without irreversible damage to these systems or the life support process that they enable. In this context, the notion of environmental utilisation space offers an interesting analytical concept (see Weterings and Opschoor 1994), as this space determines the regenerative capacity of the environment and the way resources are utilized. The latter notion is also relevant, since natural resources can in general be meaningfully subdivided into non-renewable resources (e.g., oil, iron, etc.), semi-renewable resources (e.g., soil, water) and renewable resources (e.g., forests, fish, crops). It seems, for example, plausible to assume that in case of non-renewable resources a residual stock must be maintained up to a level which will ensure sufficient time for finding substitutes (in most cases, at least one generation). In the particular case of agriculture the two basic resources are water and soil (see UNEP 1992). This means that ideally water and soil indicators have to be included in any sustainability and security analysis.

For example, with reference to water quality such indicators may relate to per capita annual water use (for both productive and consumption purposes), water pollution per capita (e.g., in terms of BOD) and water purification indices. In various studies (e.g., FAO 1991) it has been shown that in particular the irrigation efficiency of water is often low (with a water loss of up to 60%). Also the use of pesticides, herbicides and fertilizers may deteriorate water quality, so that also information on the use of these contaminants would have to be included.

After our discussion of the choice of specific indicators, amongst others in relation to the development stage of an area, we will now in the next section pay attention to the second issue, viz. the reference values for these indicators.

5. Reference Values for Sustainability and Security

The previous section was mainly devoted to the identification and classification of various sustainability indicators. We argued that there is no generic set of such indicators, as site-specific conditions, policy preferences and socio-economic conditions determine the relevance of each specific indicator for policy-making. The same remarks also apply to the interpretation to be given to quantitative values of such indicators. The question whether a certain socio-economic and environmental resource development is balanced - now and in the long run - is co-determined by value statements in a political context which may differ over space and time. Nevertheless, certain developments can be classified as clearly unsustainable (e.g., if they lead to irreversible soil erosion, desertification or unlimited extraction of scarce ground water). In this context, the notion of **carrying capacity** is of great importance, as it indicates the maximum environmental resource use that is still (marginally) compatible with an ecologically sustainable economic development. This means that this concept refers to a threshold value that cannot be exceeded without causing unacceptably high damage and risk to the environment. This carrying capacity concept is sometimes also referred to as environmental utilisation space or maximum environmental capacity use (see Weterings and Opschoor 1994). In order to emphasize the need for unambiguous quantification, we will use in the remainder of this paper the notion of a **critical threshold value** (CTV). A CTV is a numerical normative expression for an indicator. In case of a cost indicator (e.g. environmental decay, resource extraction etc.), it represents the maximum value of the indicator that is still acceptable at the margin. Exceeding this critical value implies definitely a violation of sustainability or security conditions.

It is an interesting question how a CTV can be assessed. Clearly, it has to be based on solid scientific research concerning e.g. resource availability or human health effects. This means that scientific information and expert opinion are of critical importance. In addition however, it ought to be recognized that several CTV’s have by definition a policy meaning (e.g., on the acceptable level of access to resources), so that there is of course a policy involvement in the specification and numerical assessment of CTV’s.

Clearly, for each sustainability or security indicator - be it environmental or socio-economic - a separate CTV has to be determined, so that the entire set of CTV’s may act as a reference system for judging actual states or future outcomes of scenario experiments. If for an indicator holds ‘the lower the better’, then its corresponding value means that a level higher than the CTV value signifies a dangerous or threatening development which is in a strict sense unacceptable. Clearly, a value of a sustainability or security indicator that is lower than CTV is in principle acceptable or desirable. The reverse reasoning applies to benefit indicators. We will use here in our interpretative analysis - for the sake of simplicity - only cost indicators, as benefit indicators can easily be re-scaled into cost indicators.

We may now assume - after re-scaling - the following range of values of each sustainability indicator S:

$$0<S < CTV = 100$$

This can easily be depicted in the following way:

```
                                   CTV
|-- ----------------------------- -|
0                                 100
```

It goes without saying that the concept of CTV's has to be used with great caution. It is based on existing knowledge which may be specific for a given area, for local socio-economic and natural conditions, and for particular local/regional policy ramifications. Furthermore, some natural conditions may have a resilience, so that after a temporary time span of violating critical threshold conditions a return to a sustainable development or an environmental security pathway may take place.

A major problem faced in practice is thus the fact that the CTV level is not always scientifically unambiguous. In certain areas and under certain circumstances, different experts and decision-makers may have different views on the precise level of a CTV. It may even happen that a CTV is fuzzy in nature, so that then fuzzy assessment methods have to be used (see Munda 1995).

A relatively simple and manageable approach to the above uncertainty problem is to introduce a band width for the corresponding value of the CTV, defined as CTV_{min} and CTV_{max}, respectively. This band width mirrors the minimum and maximum range of CTV values, expressed by experts or policy-makers. CTV_{min} indicates a conservative estimate of the maximum allowable threshold of the corresponding sustainability or security indicator (min-max condition). CTV_{max} on the other hand refers to the maximum allowable value of the sustainability or security indicator beyond which an alarming development will certainly start (max-max condition). This can be represented as follows:

```
                                 CTVmin     CTV      CTVmax
|---------------- ------------ ---------- ----|----------|-- ----
0          A                          B    100     C      D
```

The line segments can now be interpreted in the following imaginative way:

- area A: **'green'** flag: no reason for specific concern
- area B: **'orange'** flag: be alert
- area C: **'red'** flag: reverse trends
- area D: **'black'** flag: stop further growth

This 'flag' model is a visually appealing way to confront decision-makers with the state of affairs in a certain area. It can also be represented in a computerized way by colour graphs. In this way, the basic information for making tradeoffs between conflicting objectives is available in a systematic data base.

The main problem is now that normally we have multiple sustainability and security indicators, so that the question is how to manage a complex system in case of different perceptions or views on critical values of multiple indicators. This can be carried out by using overlay techniques for each of the indicators concerned. This can be illustrated by means of Figures 4-6.

6. An Assessment and Evaluation Approach to Sustainable Development and Environmental Security

In the previous section, the indicator values could only be compared with their own threshold conditions and with outcomes of new states for the same indicator. The typology used enabled us to infer conclusions on actual or predicted socio-economic and environmental states of an agricultural system, while respecting local expertise and site-specific or sector-specific conditions. It puts a heavy claim on the establishment of the CTV_{min} and CTV_{max} values, but it is clear that unambiguous conclusions can hardly be drawn on sustainability and security issues in agriculture, if no normative standards or threshold values are known. A mutual comparison between different indicators requires a joint assessment and evaluation.

In order to analyse conflicts and complementarities among the indicators, ideally we would have to construct a **comprehensive system's model for agricultural activities** (per sector and per region) depicting in an empirical quantitative way the various economic, social and environmental phenomena of interest. Such a modelling activity could take the form of either an econometric model validated by empirical data on solid statistical grounds or a simulation model calibrated (at best) by plausible system's parameters. In order to control for unmanageable model size, sometimes a hierarchical or modular structure would be preferable. In any case, such an integrated modelling approach would enable researchers to trace the precise quantitative implications of various types of human influences to be envisaged and assessed simultaneously. Unfortunately, in only a limited number of cases such an ambitious model does exist, so that in many cases one has to resort to a more pragmatic approach (see Nijkamp and Blaas 1994).

A first approach would then be to build **a relatively simple cause-effect model** including only a few key variables. Such an exercise is not comprehensive (e.g., in terms of feedback loops), but it nevertheless encapsulates the most important

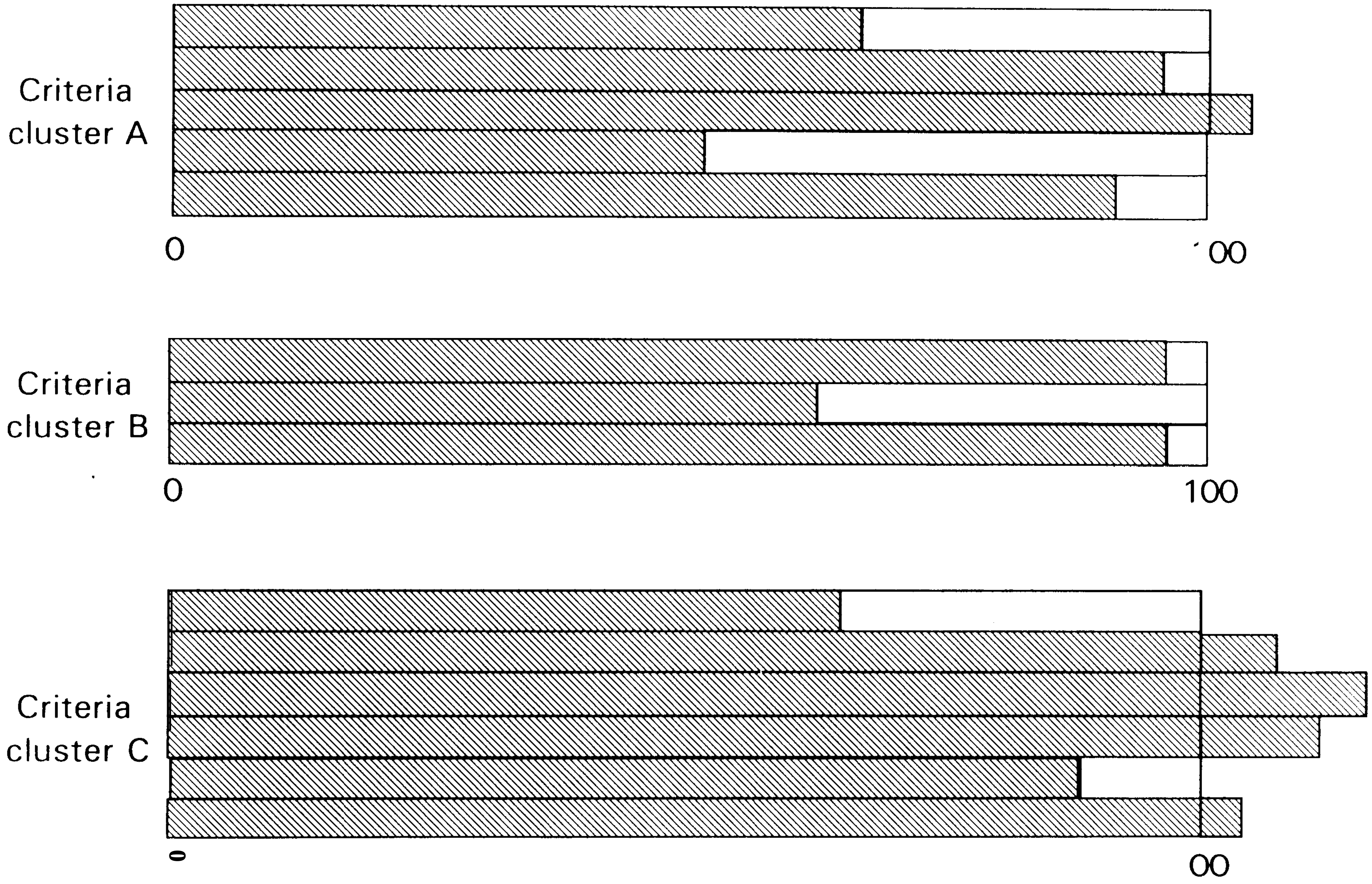


Figure 4. Reference (zero or initia situation 0

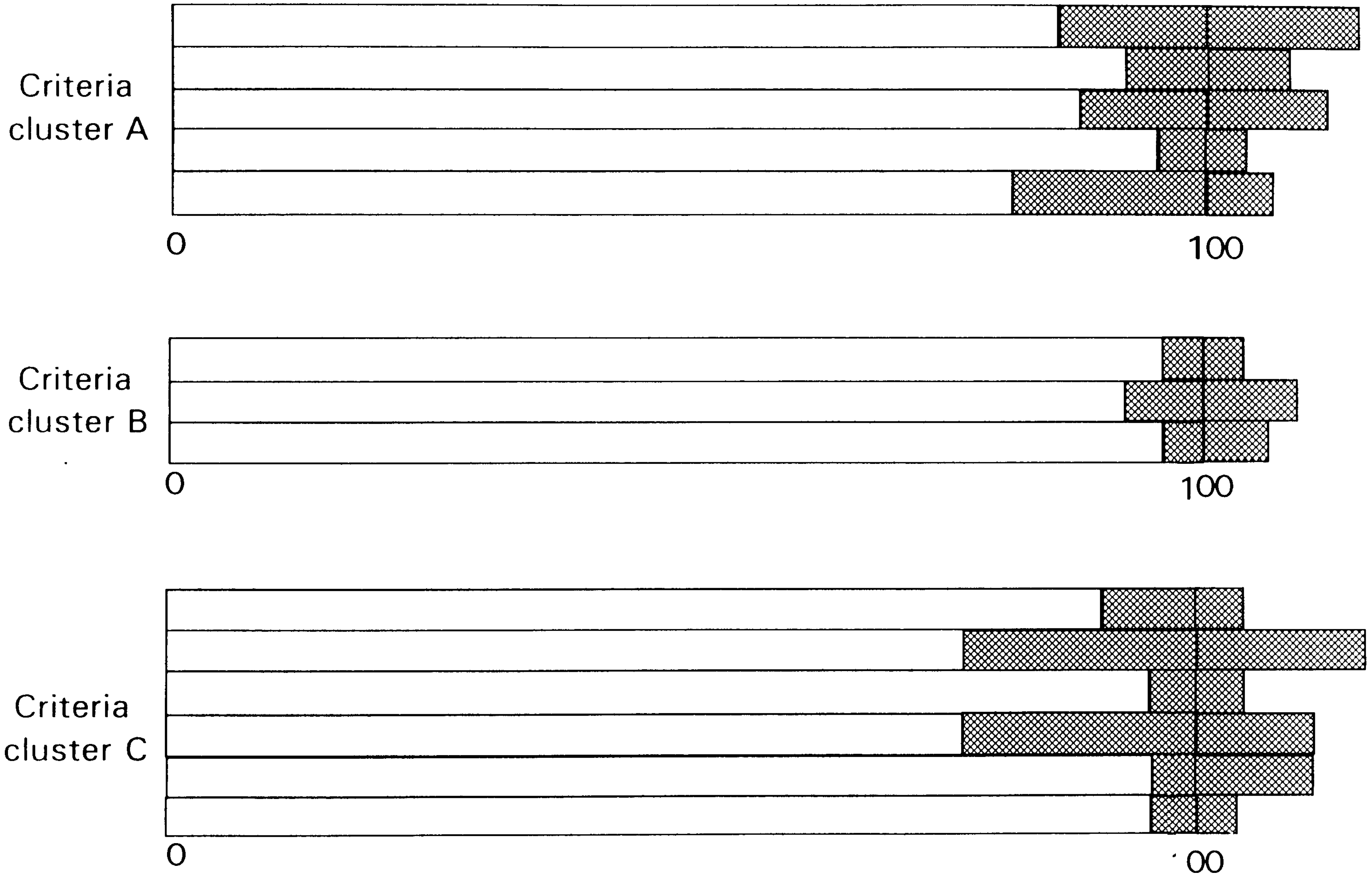


Figure 5. Ranges of critical threshold values

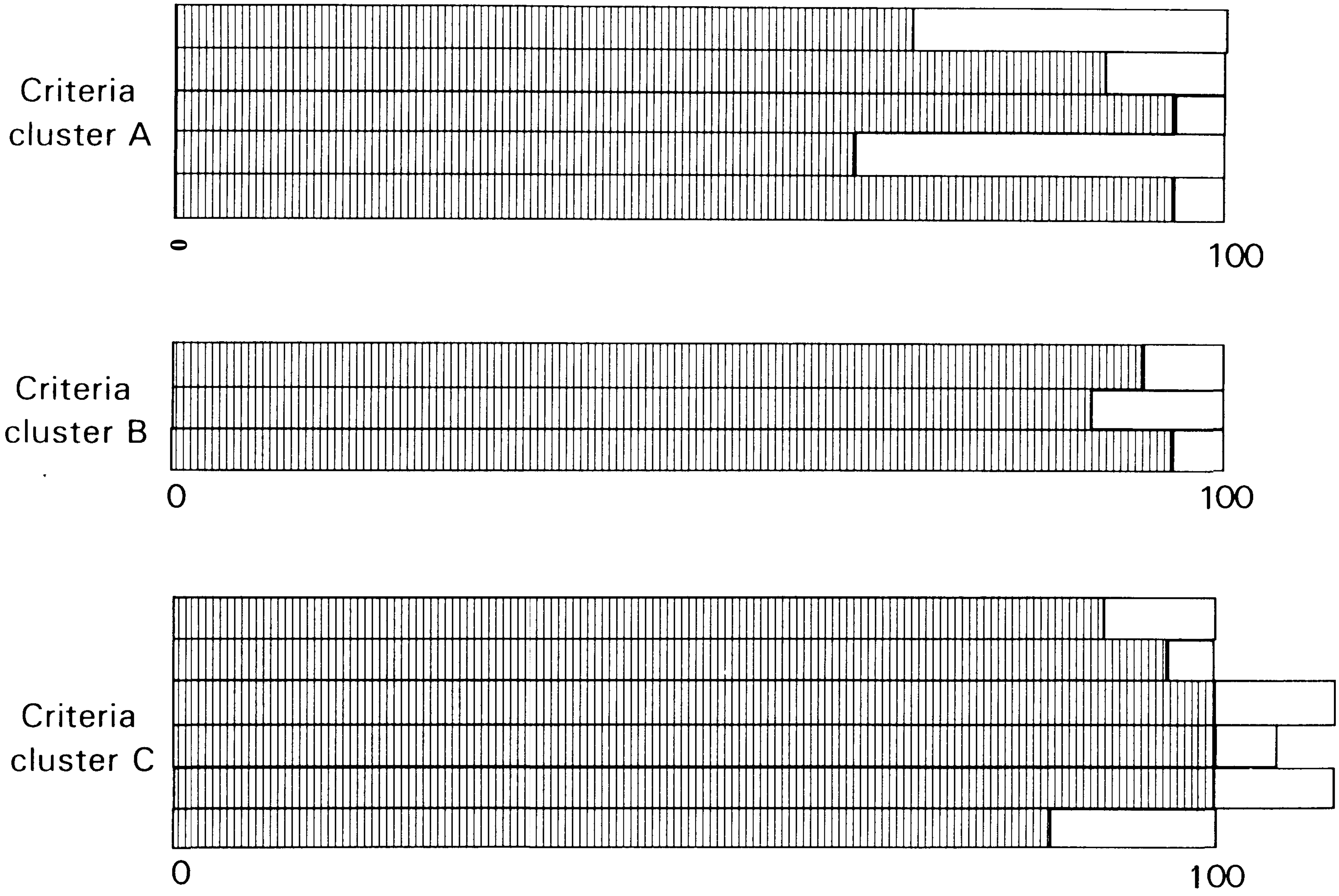


Figure 6. Results of new situation 1

key forces of an agricultural system. For example, the proportion of the volume of soil loss through erosion resulting from each crop (or group of crops) may be analyzed by investigating the effects of policy actions in favour of specific crops. Problems of incompleteness, uncertainty and stochasticity can then be handled by exercising systematic sensitivity analyses in a broad range of uncertainty intervals of parameters used. For example, how much erosion would be caused by some percentage shift in demand for given crops, all other things being equal. Such partial sensitivity analyses might certainly be helpful in complex sustainability and security trade-offs. See for an illustrative example of such experiments the TARGETS 1 .O model developed by RIVM in the Netherlands (see Figure 7).

A second approach would be based on an **ad hoc analysis,** where all available information is used to assess the foreseeable consequences of various types of human intervention. Sources of information might be: expert's views, Delphi techniques, producer's surveys, comparative studies on similar cases, simple correlation tech- niques and the like. The uncertainties involved in such an exercise might then be traced by presenting them to a forum of experts and might next be represented by broad uncertainty intervals around a central estimate of relevant variables.

Finally, recent developments in the area of **meta-analysis** have to be mentioned, where input stimuli may be connected with a wide variety of **output responses.** After the success of this approach in the medical sciences, we observe an increasing popularity of this approach in social science disciplines, including environmental sciences (see for a survey Van den Bergh et al. 1997, and Button and Nijkamp 1997).

A major problem which so far has not yet sufficiently been addressed in environmental assessment models is the **spatial** scale of analysis. Although the problems are well-known for a long period, the spatial resolution of sustainability problems in land use activities is still a difficult task. Fortunately, modern GIS techniques have been very instrumental in developing interactive modes between quantitative modelling and spatial mapping. It may be expected that in the near future the potential offered by GIS will enable to have a close correspondence between spatial analysis and spatial representation at all relevant geographical scales (see also Fischer and Nijkamp 1993).

It is clear that a solid impact analysis is the Achilles' heel in environmental sustainability and security analysis. Much effort will be needed to build up a mature type of agricultural sustainability analysis. In this context, scenario analysis has become a popular tool. This will now briefly be discussed.

After our discussion of sustainability indictors, critical threshold values and assessment techniques, it is now important to integrate the previous building blocks in a comprehensive decision support tool. In general, policy analysis deals with 'what-if' questions, which means that out of a set of choice options the most plausible one has to be identified, based on a careful assessment and evaluation of all relevant impacts of a policy measure in the agricultural sector. In practice, policy-makers are often not interested in the identification of a single future

TARGETS 1 .O
modular perspective

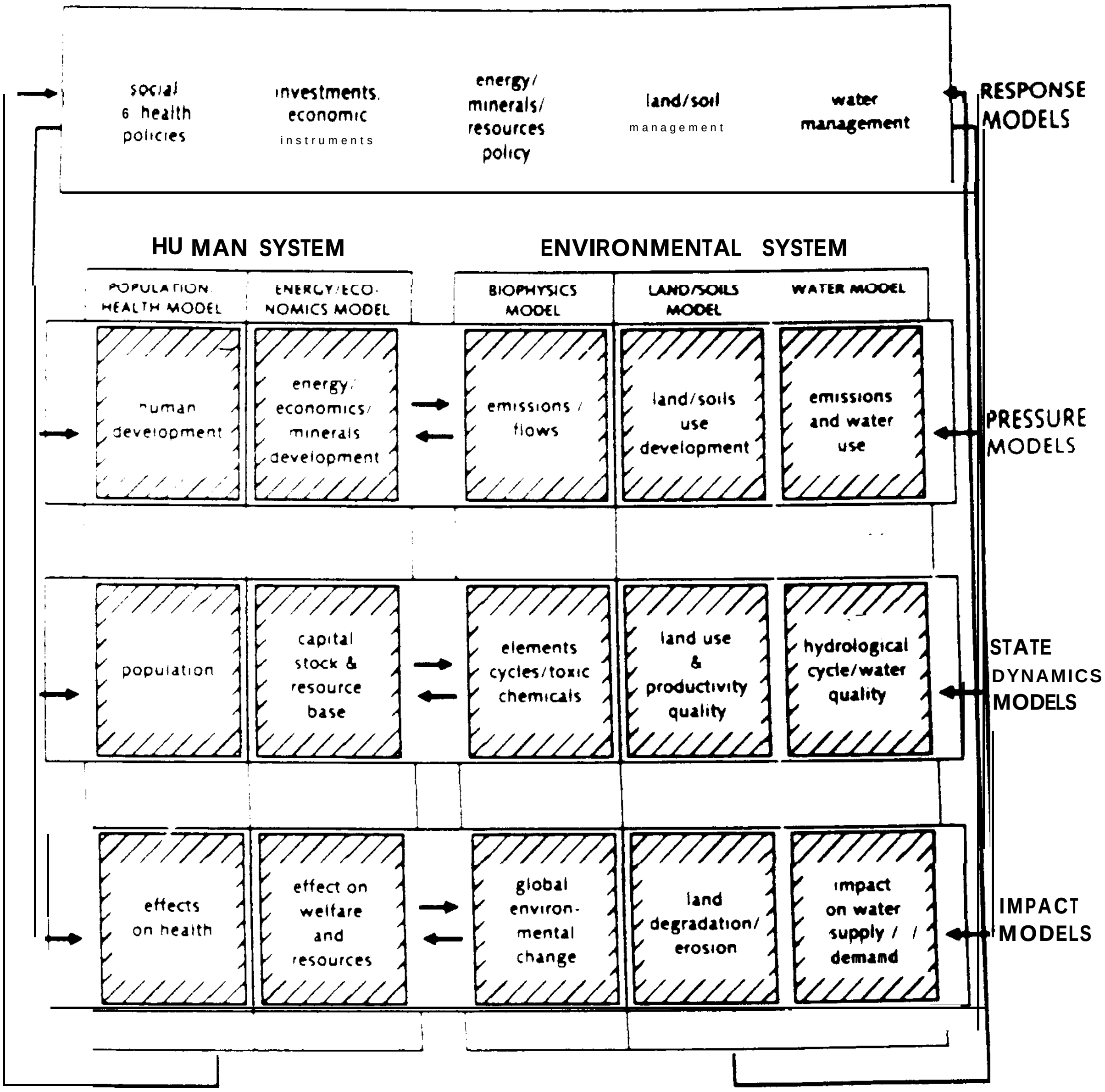


Figure 7. TARGETS 1.0 Model

state, but rather in a set of possible states, so that there remains sufficient scope for flexibility in decision-making. This means that a series of choice options has to be generated, based on a systematic scanning of uncertain future choice possibilities.

A systematic way of scanning such choice options is **scenario analysis,** through which a set of possible futures of an agricultural system - characterized by a comprehensive set of values of sustainability indicators - can be identified. Such scenarios may originate from different assumptions on future pathways for agriculture:

- **exogenous** change (e. g . , natural conditions, international agreements etc .)
- **behaviourial** change (e.g., transition to other types of crop production, new price settings etc.)
- **policy response** (e. g . , deregulation, protectionism etc.)

The 'art' of scenario building is to select out of an almost infinite number of composite choice possibilities a subset of relevant feasible options. The assessment methodology described above may be used to trace the foreseeable impacts of these scenarios (in terms of consequences for sustainability indicators), while the judgement framework based on reference values via critical threshold levels may be used to identify the degree of sustainability of each of these future scenarios. In this context, expert-based scenarios based on available knowledge on local circumstances may be helpful (see Nijkamp et al. 1997).

Clearly, in principle, it may be possible to identify the most plausible ('optimal') scenario by applying a multi-objective or multi-criteria analysis to the above mentioned choice problem (see also Giaoutzi and Nijkamp 1994). We refer here in particular to Hermanides and Nijkamp (1997) and Nijkamp and Ouwersloot (1997) for an application of multicriteria decision techniques in the framework of the above described 'flag' model.

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