Uncertainty in integrated assessment modelling

a cultural perspective based approach

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Design: Martin Middelburg, studio RIVM
Lay-out, production:Martin Middelburg, studio RIVM

National Institute of Public Health and the Environment (RIVM)
P.O. Box 1
3720 BA Bilthoven, The Netherlands
Tel: 31 30 744044
Fax: 31 30 252973
E-mail: cwmmarjo@rivm.nl

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SUMMARY

Uncertainty plays a key role in global integrated assessment modelling. Identifying, illuminating and clarifying uncertainties in integrated assessment models is therefore a central issue in the research of the Global Dynamics and Sustainable Development group of the National Institute of Public Health and Environmental Protection (RIVM, the Netherlands). Currently available uncertainty analysing techniques suffer from the fact that they are unable to render all sources and kinds of uncertainty explicit, that they provide no systematic, coherent and consistent clusters of uncertainties and that they fail to explain and clarify uncertainties in a manner understandable and acceptable by decision-makers.

In this report an approach is introduced in which uncertainty due to subjective judgment and disagreement among experts is identified, illuminated and clarified, and in which it is possible to cluster uncertainties in a systematic, coherent and consistent way. Because subjective judgment and disagreement arise due to the fact that people have adopted various perspectives, we propose perspective-based alternative model routes as a complementary methodology to articulate those uncertainties. Alternative routes are model interpretations in which the uncertainties are coloured with the bias and preference of a certain perspective. To this end, we need a consistent and coherent typology of perspectives, which is theoretically and empirically underpinned.

In state-of-the-art social science Cultural Theory as expounded in Thompson *et al.* (1990), together with their conception of cultural perspectives, is generally considered to be the best available classification of perspectives. The cultural perspectives are characterized by two dimensions: 1) how the world is seen (world view) and 2) how the world should be managed (management style).

Notwithstanding the rigid schematism of the cultural perspectives, they serve as a useful framework in operationalizing the notion that differing perspectives are significant. With the cultural perspectives as heuristic device, alternative model routes provide consistent and coherent chains of interpretations of crucial uncertainties associated with subjective judgment and disagreement among experts.

In order to improve the communication of uncertainty to decision-makers, we need to strike a chord with them in terms of concepts used in policy. Decision-makers are familiar with the concept of risk as means to evaluate policy strategies. We therefore seek to explore the use of alternative model routes as means to translate the concept of uncertainty into risks associated with specific policy strategies. The favoured management style of each perspective is juxtaposed with the alternative two world views. Such experiments teach us what might happen in the event of reality failing to correspond to a perspective's world view. Alternative model routes, which are themselves combinations of world views and management styles, can be used to assess the risks of a specific strategy in the face of uncertainty.

We realize that, in principal, it would be impossible to identify and illuminate all of the uncertainties in any model, let alone in an integrated assessment model. Inherent to the character of uncertainty is that one cannot delineate everything which is unknown. We aim at the articulation of the most important and significant perspective-related uncertainties associated with subjective judgment and disagreement occurring in integrated assessment models as our contribution to methodologies in the field of uncertainty analysis. We propose certain selection criteria to indicate the relative importance in order to arrive at a workable and manageable set.

We applied the above methodology to the fertility submodel and the climate part of the global cycles submodel of the TARGETS model, to assess the usefulness and limitations of this kind of uncertainty analysis for both the human and the environmental system. The integrated assessment model TARGETS, the acronym for: **T**ool to **A**ssess **R**egional and **G**lobal **E**nvironmental and Health **T**argets for **S**ustainability, is currently being developed at RIVM.

Experiments with perspective-based alternative model routes, using a preliminary version of the fertility submodel, have been carried out. Similarities in the simulated historical trajectories suggest that history can be interpreted along each of the cultural perspectives. We need to subject the alternative model routes to a sensitivity analysis to evaluate whether

some of the parameters, which do not substantially differ in the various routes, dominate the model outcomes. Such a sensitivity analysis of the fertility model will be carried out during the second quarter of 1995.
Using the alternative and consistent interpretations and coherent clusters of the uncertainties, differences in future projections can be motivated and explained, instead of merely arriving at minimum values, maximum values and 'best-guess' values. In this way, scenario choices can be systematically motivated, instead of being based on the 'rules of thumb' in the pragmatic approach which has hitherto been adopted in integrated assessment modelling.

Analysis of the juxtaposition of the two alternative world views with the preferred management style indicate that in the event that reality fails to correspond to a perspective's world view 1) the egalitarian strategy (where the main focus is on education policy and prohibition of abortion) might cause serious problems, 2) the hierarchistic management style (i.e. main focus on family planning and legalisation of abortion) does not prevent the total population from passing the hierarchistic ultimate limit of 20 billion people and 3) the do-nothing policy of the individualist results in differing futures. Such experiments can be used to analyse and improve the strategies. In this way, uncertainties are no longer hidden, but rather used in a constructive manner as building blocks in fashioning a new methodology in scenario development. Such an assessment assists decision-makers in selecting the most 'promising' strategies. 'Promising' is here defined as meaning 'as close to the perspective's preferred situation as possible with as little risk as possible'.

Perspective-based alternative model routes enable us to attribute the overall uncertainty associated with fertility projections to (relatively) specific sources of uncertainty. Such insights may be used to (re)write the research agenda. The alternative model routes enable demographic scientists to readjust projections systematically and in an insightful manner when new scientific evidence and new empirical facts have been established.

Due to delays in the development of the CYCLES model, it was not yet possible to implement alternative model routes in the climate part of TARGETS . The case-study on the climate issue should therefore be considered as a feasibility study, leading to narrative descriptions of perspective-based alternative model routes for the climate change issue. The model routes will be implemented in the second quarter of 1995 in order to assess and to explain the consequences of perspective-related uncertainties concerning climate change in a systematic, coherent and consistent way.

The case studies of the application of the proposed methods have, we hope, gone some way towards demonstrating that the methodology of perspective-based alternative model routes might be a fruitful one: 1) in rendering uncertainties due to subjective judgment and disagreement among experts explicit, 2) in providing coherent and consistent clusters of uncertainties, 3) as building block in fashioning a systematic methodology in scenario development, 4) as approach to translate the concept of uncertainty into risks associated with individual response strategies and, 5) in facilitating communication between scientists and decision-makers.

Alternative model routes will be developed and implemented in all submodels of TARGETS, which will enable integrated analyses of uncertainties in future projections. Such integrated experiments might be of use for, for example, the United Nations Environmental Programme (UNEP) and the Human Dimensions of Global Environmental Change Programme (HDGECP).

1. INTRODUCTION

The concept of uncertainty plays a key role in global integrated assessment modelling, because forecasting future global change and its consequences for human society is beset with many uncertainties (Rotmans et al., 1994). However, in spite of these uncertainties, decision-makers cannot afford to wait for perfect models and total understanding. Global integrated assessment models, defined as models which analyse the phenomenon of global change from an integrated perspective, are designed to assist decision-makers in setting priorities and developing adequate response strategies. Rather than being prediction tools, global integrated assessment models are interpretative forecasting tools, which can amplify insights into the present and future driving forces underpinning our complex social, economic and ecological structures (Rotmans, 1990). In many global integrated assessment models the imperfectness and lacunae in current scientific knowledge are as it were hidden away. Ignoring or suppressing uncertainty in integrated assessment models often results in a misplaced sense of confidence in numbers. Addressing the issue of uncertainty by rendering uncertainties explicit is of vital importance in enabling decision-makers to identify the major sources of uncertainty in the phenomenon of global change, and in helping them to anticipate possible future developments.

Because integrated assessment models are intended as means of capturing an entire cause-effect chain, such models are prone to an accumulation of uncertainties and the issue of uncertainty is therefore of crucial importance. Currently available methods, such as Monte Carlo sampling, are unable to render all sources and types of uncertainties explicit in a coherent and consistent way. We therefore propose to investigate a complementary method of uncertainty analysis by which uncertainties arising from neglected sources, i.e. subjective judgment and disagreement among experts, can be analysed. We will argue that subjectivity and disagreement occur due to the fact that people have adopted different perspectives. This allows us to employ a methodology which uses cultural perspectives as points of application in evaluating uncertainties in integrated assessment models, by creating perspective-based alternative model routes.

By way of example, we apply this method to the global integrated assessment model TARGETS, the acronym for: **T**ool to **A**ssess **R**egional and **G**lobal **E**nvironmental and health **T**argets for **S**ustainability, currently being developed at RIVM (Rotmans *et al.*, 1994). *Figure 1.1* gives a scheme of the TARGETS modelling framework. The TARGETS framework basically consists of a population and health model, a resources/economy model, a (biophysics) cycles model, a land model and a water model. In this study we apply the methodology to two of the submodels in TARGETS, namely: the fertility submodel as part of the population and health model and the climate part of the global cycles model.
The TARGETS model serves to explore the long-term dynamics of global change, by means of which an integrated assessment can be performed, on a global scale, of the quantitative linkages between demographic, social and economic processes, biophysical processes and effects on ecosystems and humans. Furthermore, the TARGETS model can be used to develop concrete strategies for sustainable development. The model should be regarded as an aid to the formulation of possible projections for the future, and not as a means of generating predictions as such. The TARGETS model has as its main objective the operationalization of the concepts global change and sustainable development. The disturbance on a global scale can be represented by a set of interrelated and inextricably interconnected cause-effect chains. Cause-effect chains are aggregated into a Pressure, a State, an Impact and a Response subsystem. The colums in *Figure 1.1* represent the causal chains, while the rows represent cross-linkages between the elements of the causal chain. The different boxes in the scheme denote submodels or modules which can be represented by sets of indicators or indices.
Given the complexity and dynamic nature of the mutual interdependencies, the integrated systems approach can help to foster understanding of the causal and mutual relationships between processes within the human and environmental system. Integration has two dimensions: 1) vertical integration, i.e. capturing as much as possible of the cause-effect chains and 2) horizontal integration, i.e. the integration of different cross-linkages and interaction between the various subsystems.
For the development of the TARGETS model, a top-down approach is chosen, whereby the analysis starts at the highest aggregation (abstraction) level,

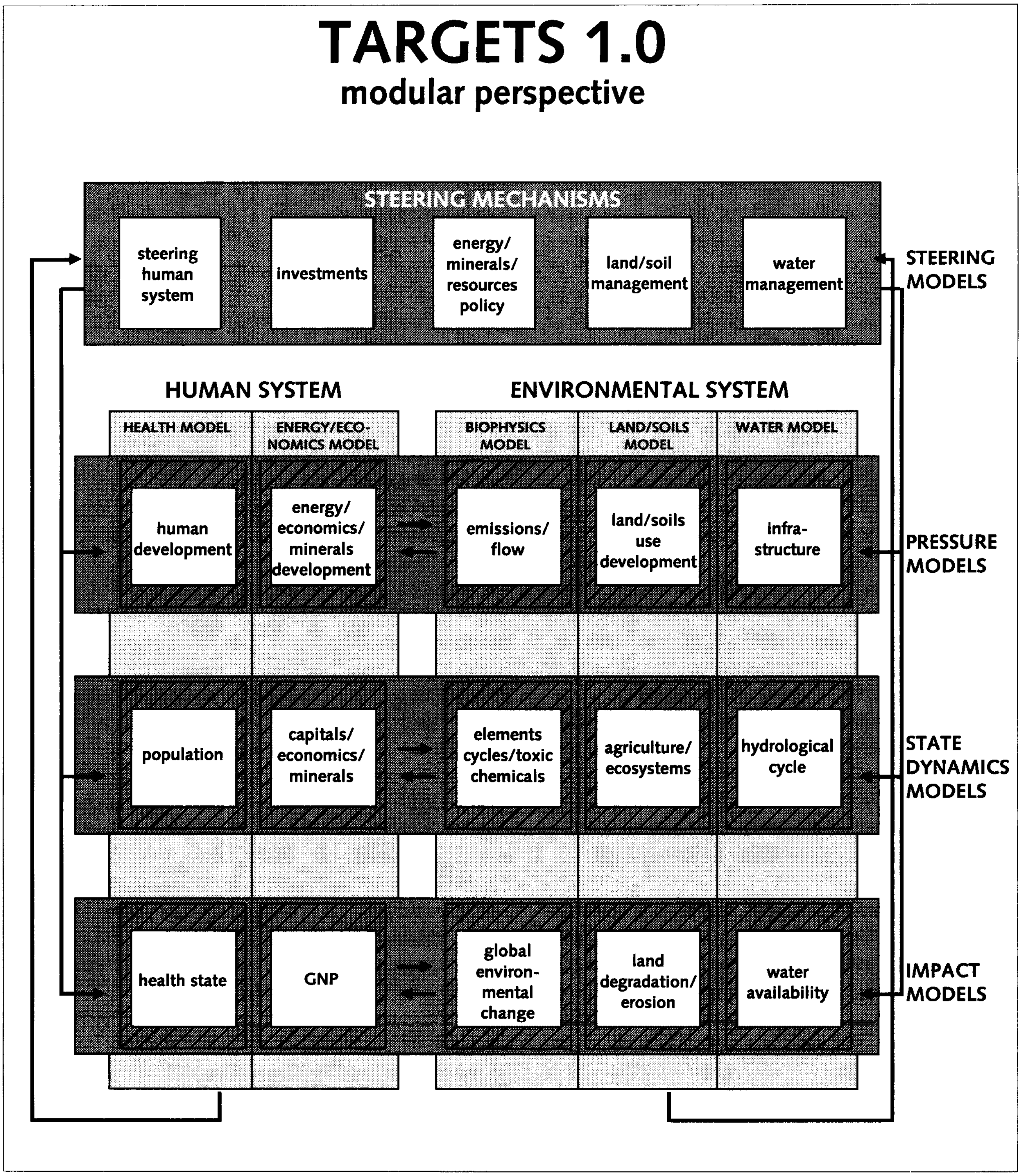


Figure 1.1: Modular perspective of TARGETS

i.e. the global level, considering the planet Earth as a whole. In the next phase the model will be disaggregated to the level of economic world regions, river basins and ecosystems, using regional data sets. This implies that case studies will be carried out.

Not only the model itself, but also the use of the model is one of the focal points of the research programme. A great deal of attention will therefore be paid to the presentation of relevant information generated by the model in an insightful manner, which is of crucial importance in the communication process between science and policy-making. This necessitates the 'opening' of models, an exercise which ranges from the construction of a model which can be used interactively, to the creation of strategic planning exercises (De Vries *et al.*, 1993). It is therefore to be expected that the TARGETS model is not only of use as means of communication between science and policy making, but also between the natural and social sciences.

In sum, the TARGETS model is not a traditional model, in the sense that:

* it is not intended to incorporate all entities, processes and feedbacks supposed to be relevant. TARGETS consists of reformulated, simpler versions of more sophisticated and complex aspect-compartment models (expert models), so-called metamodels.
* the model is open (transparent) and can be used interactively.
* incremental changes in the subsystems may cause considerable, unexpected changes in the whole system. TARGETS will be a composite framework which may show nonlinear and complex, perhaps even chaotic, behaviour.
* the concept of uncertainty is explicitly addressed.

The paper is structured as follows: Chapter 2 elucidates the concept of uncertainty and some basic characteristics of the Cultural Theory (Thompson *et al.*, 1990) and the resulting cultural perspectives, which introduces our methodology of perspective-based alternative model routes. Chapter 3 and 4 present the case studies on the fertility submodel and the climate part of the global cycles model respectively. In Chapter 5 some concluding and evaluative remarks concerning the potentials of our perspective-based uncertainty analysis are made.

2. BACKGROUND AND METHODOLOGY

2.1. The concept of uncertainty

The concept of uncertainty can be elucidated in a multiplicity of terms and the variety of sources and types of uncertainty can cause considerable confusion. Several attempts have been made to classify the different sources and types of uncertainty, and the most important of these efforts will briefly be discussed below.

2.1.1. Sources of uncertainty

Uncertainty is primarily due to our incomplete knowledge and inadequate understanding of social, economic and ecological processes. In other words, uncertainty arises as a result of: value-based judgments, lack of information, inadequate information, incompatible data and variability. Where integrated assessment models representing state-of-the-art knowledge are concerned, various sources of uncertainty can be distinguished, namely: 1) statistical variation, 2) subjective judgment (systematic error), 3) linguistic imprecision, 4) variability, 5) disagreement among experts and 6) approximation (Morgan and Henrion, 1990).

Subjective judgment and disagreement originate from different interpretations of the blind spots and are primarily due to incomplete knowledge and differences in understanding. That differing interpretations exist can only be due to the fact that people have adopted different perspectives (Morgan and Henrion, 1990; Thompson *et al.*, 1990; Schwarz and Thompson, 1990; Rayner, 1991; Wallace and Norton, 1992; De Vries *et al.*, 1993; Rotmans *et al.*, 1994). We therefore propose to refer to uncertainties arising from subjective judgment and disagreement as perspective-related uncertainties.

Inherent randomness is sometimes distinguished from other sources of uncertainty, in being irreducible even in principle. For example, in assessing the environmental impact of an accidental radioactive emission from a nuclear power plant, the wind speed and direction at that time would be crucial. The best that can be done is to model the variability based on the basis of wind rose data, i.e. the empirical frequency distributions of wind velocity. Even if we could know the exact future date of the release, the inherent randomness of the wind would make it impossible to arrive at perfectly reliable predictions.

2.1.2. Types of uncertainty

Morgan and Henrion (1990) distinguish three types of uncertainty: *uncertainty in* technical, scientific, economic and political *quantities, uncertainty about* the *model structure* (i.e. uncertainties about the appropriate functional form of technical, scientific, economic and political models) and *uncertainties arising from disagreements* among experts about the value of quantities or the functional form of models. A major shortcoming in their classification is that disagreement is used both as a type and a source of uncertainty, whereas, in our opinion 'disagreement' should be considered purely as a source of uncertainty associated with models, and not as a type of uncertainty.

An alternative classification is based on the distinction drawn by Funtowitcz and Ravetz (1989) between *technical uncertainties* (concerning observations as opposed to measurements), *methodological uncertainties* (concerning the appropriate choice of analytical tools) and *epistemological uncertainties* (concerning the conception of phenomena). For the purpose of illuminating the uncertainties in the TARGETS model the types of uncertainty are aggregated to two categories, based on the subdivision of the Earth's system into the human and environmental system (Rotmans *et al.*, 1994):

1. *scientific uncertainties*: those occurring in the environmental subsystem which arise from the degree of unpredictability of global environmental change processes
2. *social and economic uncertainties*: those occurring in the human subsystem which arise from the degree of unpredictability of future geopolitical, socioeconomic and demographic evolution

The distinction drawn by Funtowitcz and Ravetz can be seen as identifying the types of uncertainties associated with models in general, whereas the classification put forward by Morgan and Henrion can be used to identify the loci in the model at which uncertainties can be found. Rotmans' subdivision is used to classify the uncertainties within the TARGETS-model. We depict the relations between sources and types of uncertainty in *Figure 2.1.*

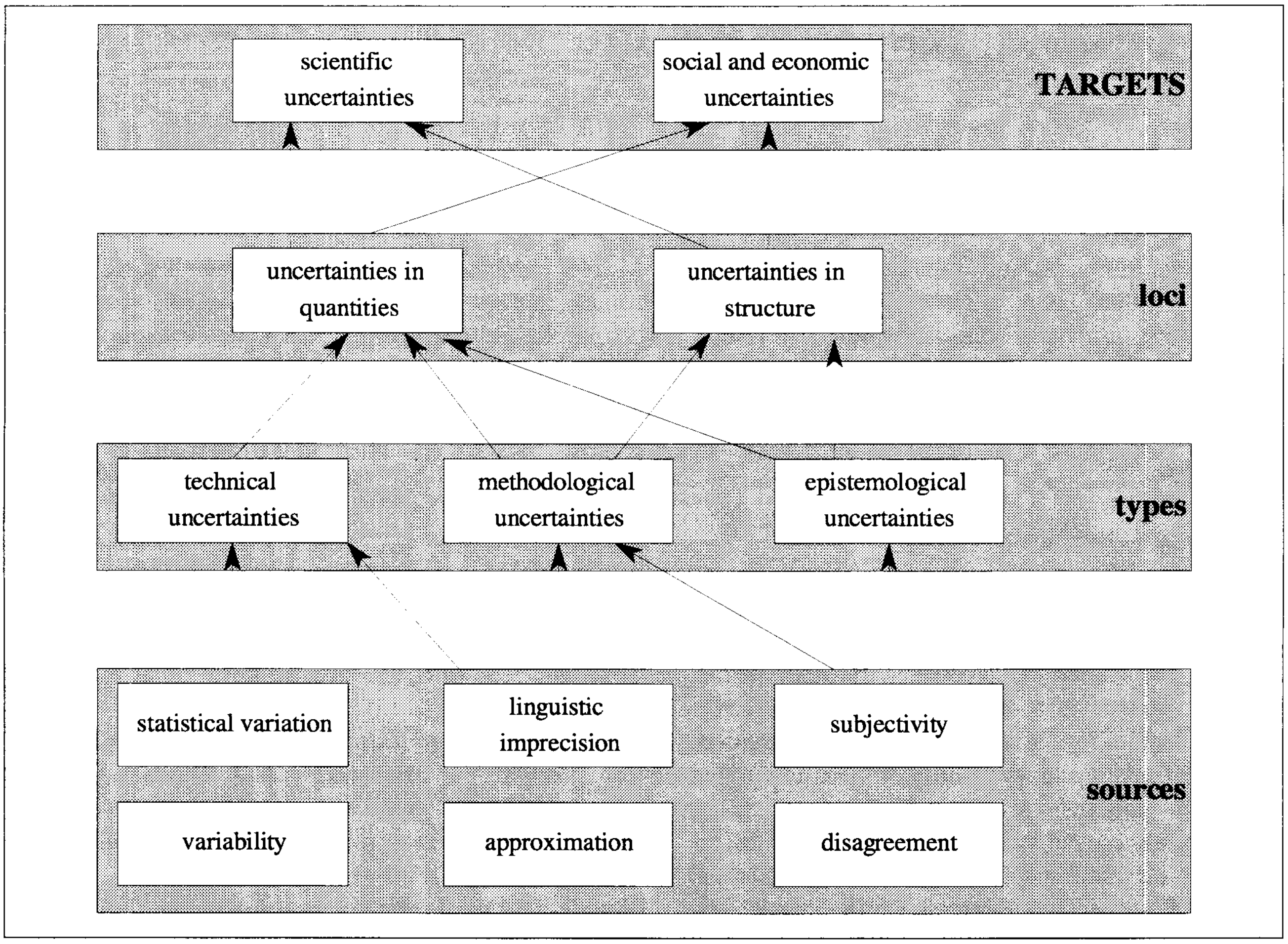


Figure 2.1: Typology of uncertainties

2.1.3. Uncertainty in quantities

Model quantities allow a distinction to be drawn between variables and parameters. In system dynamic terms, variables are time-dependent while parameters do not vary in time. Variables and parameters in integrated assessment models can be further characterized as follows (Morgan and Henrion, 1990; Rotmans *et al.*, 1994):

- *empirical quantities*: observable and measurable properties of real-world systems being modelled;
- *value variables/parameters*: constructed variables/parameters representing aspects of the preferences of the modeller, the decision-makers or the people they represent;
- *steering variables*: quantities over which the decision-maker exercises direct control in the model;
- *state variables*: representing the state of the system at a certain moment under certain conditions;
- *auxiliary variables/parameters*: introduced because of computation or programming rules, these variables/ parameters have no independent meaning.

The classes are not mutually-exclusive: quantities classified as steering variables or state variables are simultaneously either empirical quantities or value variables/parameters. Nevertheless the distinction between 'steering variables' and 'state variables' is drawn because the respective terms 'state' and 'steering' signify the role the quantity plays within the model. The differences between empirical quantities and value variables/parameters are also a matter of context, which might complicate classification of the model quantities. Where uncertainty is concerned, empirical quantities and value quantities are especially important: empirical quantities constitute the majority of quantities in models intended for policy analysis; value quantities tend to be among those quantities people are most unsure about, which thus contribute most to uncertainty about which decision is best. In the case of steering variables it is suitability rather than uncertainty that matters.

2.1.4. Uncertainty about model structure

Experienced analysts often argue that uncertainty about structure is usually more important than uncertainty about quantities, and more likely to have a substantial effect on the results of the analysis (Morgan and Henrion, 1990). Notwithstanding its salient importance, there has been relatively little research on uncertainty about model structure (Janssen *et al.*, 1990). Morgan and Henrion (1990) introduce the idea of assimilating different model structures into a single model which "contains" those various structures as special cases, according to a value of one or more parameters or variables. This idea is operationalized in our concept of alternative model routes, which will be explored in Section 2.4.1.

2.2. Problem definition and objectives

2.2.1. Shortcomings in current uncertainty analysis

Deterministic estimates of minimum, maximum and best guess values used in traditional uncertainty analyses, which are based on the 'informed opinions' of experts, are often erroneous or misleading in several ways (Frey, 1992): 1) they are often biased away from the mean values of the uncertainties they represent; 2) they provide no indication to decision-makers regarding the magnitude of underlying uncertainties; and 3) they offer no indication of the key sources of uncertainty. Such estimates are not based on complete consideration of interactions among multiple, simultaneously-uncertain variables, although in the case of integrated assessment models, ignoring such interactions is to give hostages to fortune. In other words, currently available uncertainty analysing techniques do not provide a systematic, coherent and consistent clustering of the estimates of the uncertainties.
A further shortcoming is that traditional methods do not allow us to analyse uncertainty in model structure. They only address uncertainties in parameters. We, therefore, need complementary methods of uncertainty analysis which 1) enable us to analyse uncertainty not only in model parameters, but simultaneously in model variables and model structure, which 2) provide a basis on which to explain why specific estimates are used and which 3) provide reasonable clusters of the interpretations of the uncertainties.

Currently available uncertainty analysing techniques do not distinguish between the various sources of uncertainty, which makes it difficult to entangle how the uncertainty conceivably can be "reduced" (for example by additional measurements, by more detailed modelling or by consensus building). The various sources of uncertainty are the starting point of our analysis of uncertainties in integrated assessment models. Standard techniques (Janssen *et al.*, 1990) do not allow us to analyse and evaluate uncertainties arising from subjective judgment and disagreement among experts explicitly and systematically. Therefore, complementary methods which enable us to identify, illuminate and clarify perspective-related uncertainties in integrated assessment models in a systematic, consistent, coherent and comprehensible way are required.

Within policy-oriented science, much attention is paid to the problems of uncertainty in the policy context (Morgan and Henrion, 1990; Funtowicz and Ravetz, 1990; Frey, 1992). Decision-makers would prefer certainty, but are obliged to deal with uncertainty. Current methods of uncertainty analysis fail to bridge the gap between uncertainty as a matter of fact and uncertainty as a factor in supporting decision-makers. Therefore, we need to find ways and means by which to translate uncertainty into concepts which dovetail with the experiences and practices of decision-makers.

2.2.2. Objectives

The focus of the present study is to find ways in which to mobilize the idea that subjective judgment and disagreement occur due to the adoption of different perspectives in order to analyse and clarify perspective-related uncertainties in integrated assessment models. To this end, we need a consistent and coherent typology of perspectives, which is theoretically and empirically underpinned. In the field of environmental issues in general, and on the issue of global climate change in particular, many worthwhile attempts have been made to distinguish various perspectives (Zweers, 1984; Riebsame, 1990; De Vries, 1989; Jastrow *et al.*, 1990; Kockelkoren, 1990; Colby, 1991; Faure *et al.*, 1993; Coward *et al.*, 1993; Dotto, 1994). In state-of-the-art social science Cultural Theory as expounded in Thompson *et al.* (1990) is generally considered to be the best available classification of perspectives. The superior value of the work of Thompson *et al.* (1990) resides in its general, methodical and systematic character. In contrast with other classifications, the types generated in Thompson *et al.* (1990) are derived from common social dimensions, which measure social restrictions upon individual autonomy.
During recent years there has been increasing recognition of the use of Cultural Theory within the context of sustainable development (see for example: De

Greef and De Vries (1991) and Vellinga (1992)). A first attempt to introduce the use of cultural perspectives as an approach enabling an uncertainty analysis of integrated assessment models has been made by Janssen and Rotmans (1994). They used cultural perspectives to determine distributions of parameter values and future scenarios. Why is Cultural Theory so promising? A review of post-war social sciences teaches us that in anthropology and in sociology 'culture' is studied on several levels. On the one hand, these fields of investigation deal with the question: 'what is culture?'. A starting point which implies that 'culture' is primarily studied at a high level of abstraction. Generalized typologies of cultures are thus not the main concern. Other branches of sociology and anthropology deal with social action in general, in which the influence of culture is merely one among many contributing factors. Hence, in these branches there is no interest in a general typology of cultural perspectives. At a lower level of abstraction within sociological and anthropological research, typologies are employed in describing a particular relatively discrete social group such as a tribe, a village, a business organization or a nation. In such cases, typologies are related to special cases, and consequently do not constitute theoretical frameworks. In other words Thompson *et al.* (1990), Schwarz and Thompson (1990) and others attempt to exploit a promising new avenue of scientific investigation. Owing a great deal to historic achievements in sociology and anthropology (e.g. in the work of Mary Douglas), Thompson *et al.* (1990) describe cultural perspectives on the level of humanity as a whole. Bearing in mind the aggregation level of global integrated assessment models, we need such a general typology in order to apply the notion of perspectives as an approach to enabling uncertainty to be envisaged in such models. Notwithstanding the rigid schematism of the cultural perspectives, they serve as a useful framework in operationalizing the broadly-accepted notion that differing perspectives are significant.

We propose to analyse "chains" of uncertainties both in model quantities and in model structure by following alternative model routes, a concept which will be considered in detail in Section 2.4.1. Suffice it here to say that alternative model routes can be seen as coherent clusters of different interpretations of the perspective-related uncertainties occurring in both quantitative and functional form. Alternative model routes should represent coherent and consistent interpretations which are viable both in the scientific and in the policy community. Cultural Theory expounded by Thompson *et al.* (1990), together with their conception of cultural perspectives, provides an appriopriate classification of coherent 'weltanschauungen' for our purposes.

In order to foster understanding and acceptance of the concept of uncertainty among decision-makers and to improve the communication with decision-makers, we need to strike a chord with them in terms of concepts used in policy. Decision-makers are familiar with the concept of risk as a means to evaluate policy strategies (Funtowicz and Ravetz, 1990; WRR, 1994; Van Asselt, 1994). We therefore seek to explore the possibility of describing and explaining uncertainty in terms of risk associated with specific policy strategies (Subsection 2.4.2.).

We realize that, in principal, it would be impossible to identify and illuminate all of the uncertainties in any model, let alone in an integrated assessment model. Inherent to the character of uncertainty is that one cannot delineate everything which is unknown. We aim at the articulation of the most important and significant perspective-related uncertainties in integrated assessment models as our contribution to methodologies in the field of uncertainty analysis. Selection criteria are discussed in Section 2.5.

2.3. Cultural Perspectives

2.3.1 Introduction

Multiple perspectives are possible because there is always sufficient uncertainty in the world to introduce bias into our convictions. 'Cultural perspectives' involve the different perceptual screens through which people interpret or make sense of the world and the social dimensions within it, whereby particular visions of reality seem more or less plausible. To elaborate this concept, Thompson *et al.* (1990) introduce the notions *cultural bias* (-shared values and beliefs) and *social relations* (patterns of interpersonal relations). By reference to these notions, a cultural perspective is defined as a more or less viable combination of social relations and cultural bias. The degree of viability of a perspective depends upon a mutually supportive relationship between a particular cultural bias and a particular pattern of social relations. Thompson *et al.* (1990) claim that five, and only five, perspectives - the hierarchist, egalitarian, fatalist, individualist and autonomous perspectives- are sufficiently viable. The adoption of perspectives is a dynamic process.

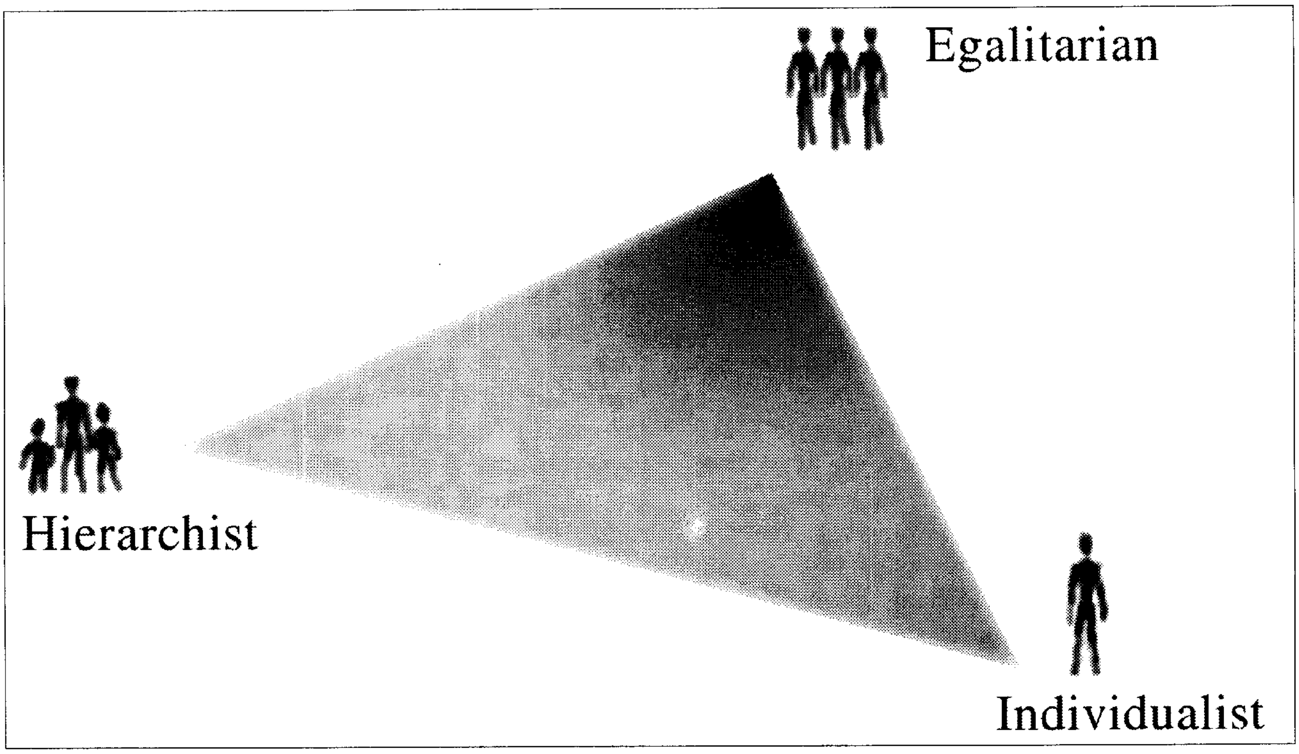


Figure 2.2: Spectra expanded by the active perspectives

Change occurs because of "surprise", i.e. the discrepancy between the expected and the actual, which is of central importance in dislodging individuals from a previously adopted perspective. Adherents to each of the five perspectives are, as it were, in competition for new adherents to their particular perspective, but are dependent on one another at the same time. In other words, all of the perspectives are needed to ensure each one's viability (Thompson *et al.*, 1990). For example, as will become clear from the elaboration of the different perspectives in this section, fatalists are necessary to hierarchists since they constitute elements which can be managed, the existence of fatalists as consuming participants in markets is essential to individualists, while the existence of both hierarchists and individualists is essential to the egalitarians to provide the institutions which act as yardsticks for egalitarianism (they can only recognize what is "fair" in contrast with what is "unfair"). For the purposes of this study, only the 'active perspectives', i.e. the hierarchist, the egalitarian and the individualist, are taken into account, so that the autonomous and the fatalist perspectives are disregarded. The hermit, as the exponent of the autonomous perspective is called, is not interested in what happens in the world, but prefers to distance himself from it. The fatalist, for whom everything is a lottery (both humans and nature being unpredictable) is likewise not examined as such. Nevertheless, the fatalist plays a significant role in the overall system. The active perspectives are at the extremes of a continuum (*Figure 2.2.*), which comprises all possible points of view. The fatalist is considered as the cultural equivalent of a 'substrate': the 'passive perspective' which determines the contours of the three-cornered contest in which the adherents to the other perspectives compete.

2.3.2. Characteristics of the active perspectives

This Subsection summarizes the characteristics of the active perspectives, which enables us to operationalize aspects of Cultural Theory as a workable framework.

Grid-group typology

Our point of departure is the grid-group typology proposed by Douglas *et al.* (1982). The term *group* refers to the extent to which an individual is incorporated into bounded units. The greater the degree of incorporation, the greater the extent to which individual choice is subject to group determination. This dimension is comparable to what Hofstede (1994) describes as *collectivism versus individualism.* A group is individualistic as the internal relationships between individuals are loosely: everyone is expected to care for oneself. A group is collectivistic as individuals are part of a close-knit group, which provides protection in exchange for unconditional loyalty. The term *grid* denotes the degree to which an individual's life is circumscribed by externally-imposed prescriptions. The more binding the prescriptions are, and the more extensive their scope, the fewer the facets of social life that are open to individual negotiations. This dimension is comparable to the concept of *power distance* (Hofstede, 1994), defined as 'the degree in which less powerful members of a group expect and accept that power is distributed unequally'.

Along the grid dimension, it is the element of social control that sets the various perspectives apart from each other. Strong group boundaries coupled with minimal prescriptions produce strong relations that are *egalitarian.* Because such groups lack internal role differentiation, no individual is granted the authority to exercise control over another. When an individual's social environment is characterized by strong group boundaries and binding prescriptions, the resulting social relations are *hierarchical.* Individuals in this social context are subject to the control exerted by other members in the group as well as to the demands of socially-imposed roles. The exercise of control (and more generally the very existence of inequality) is justified on the grounds that different roles for different people enable people to live together more harmoniously than alternative arrangements would. Individuals who are neither bound by group incorporation nor by prescribed roles inhabit an *individualistic* social context. In such an environment, all boundaries are provisional and subject to negotiation. Although the individualist is relatively free from control by others, this does not imply abstention from exerting control over others; the individualist's success is often measured in terms of the size of the following the person can command.

Views of physical nature

Thompson *et al.* (1990) claim that ideas of human and physical nature are socially-constructed and adopted by individuals according to their perspective. The concept of 'myths of nature', derived from the work of ecologists (Holling, 1977; Timmerman, 1986), can enable the cultural perspectives to be represented graphically by reference to the metaphor of a sphere rolling in a landscape (see *Figure 2.3.*). Nature, for egalitarians, is *strictly accountable*, and their idea of the world can be represented by the concept of "Nature Ephemeral" (Holling, 1977; Timmerman, 1986). For them the world is a terrifying, unforgiving place and the least jolt may trigger complete collapse. The managing institution must therefore take good care of the ecosystem: the egalitarians advocate a preventive management style (Rayner, 1991). For individualists, nature is a *"skill-controlled cornucopia"* (Thompson *et al.*, 1990), i.e. thanks to human skill nature provides resources in plenty. The individualists' idea of the world is represented by the concept "Nature Benign" (Holling, 1977; Timmerman, 1986). According to this myth, the world is wonderfully forgiving. The management institution can therefore adopt a laissez-faire attitude, that is the individualists advocate an adaptive management style (Rayner, 1991). The hierarchists see nature as being in an *"isomorphic"* (Thompson *et al.,* 1994) relation with the social realm; i.e. its rich differentiation ensuring that it is forthcoming when approached in the right way by the right people, but retributive when pushed beyond these carefully-learned bounds. This idea is represented by the myth of Nature as "Perverse/Tolerant" (Holling, 1977; Timmerman, 1986); nature is forgiving in most circumstances, but is vulnerable to the ball flying over the rim on occasion. The managing institution must therefore take steps to prevent such unusual occurrences. The hierarchists therefore advocate the exercise of control as a management style.

Views of human nature

According to Thompson *et al.* (1990) views of human nature are inextricably bound up with social relations. *Egalitarians* believe that human beings are born good but are corrupted by evil institutions. From an egalitarian perspective, human nature is not only good, but also highly malleable. Just as human nature can be corrupted by evil institutions (e.g. markets and hierarchies), so can it be rendered virtuous by constructing a noncoercive, egalitarian society. This optimistic view of human nature is essential to the viability of egalitarian social relations. For *individualists*, human nature, like physical nature, is extraordinarily stable. No matter what the institutional setting, human beings remain essentially the

Figure 2.3: Myths of Nature

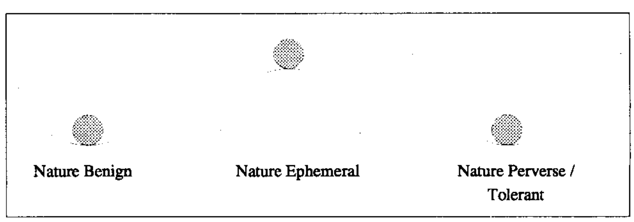


Table 2.1: Characteristics of Cultural Perspectives

	egalitarian	**individualist**	**hierarchist**
group-grid	strong group-weak grid	neither group nor grid	strong group and grid
world view			
idea of nature	accountable	skill-controlled cornucopia	isomorphic nature
myth of nature	Nature Ephemeral	Nature Benign	Nature Perverse/Tolerant
concept of human nature	born good, malleable	self-seeking	sinful
needs & resources	can manage needs but not resources	can manage needs and resources	can manage resources but not needs
management style	preventive	adaptive	control
attitude to nature	attentive	laissez-faire	regulatory
attitude towards humans	construct egalitarian society	channel rather than change	restrict behaviour
attitude to needs/ resources	need-reducing strategy	manage needs & resources upward limits of skills	increase resources
economic growth	not preferred	preferred: aim to create personal wealth	preferred: aim to create collective wealth
risk	risk-aversive	risk-seeking	risk-accepting

same, i.e. self-seeking. By regarding man as self-seeking and unmalleable, individualists can justify attempts to channel existing human nature, and their refusal to attempt to change it. *Hierarchists* believe that human beings are born sinful, but can nevertheless be redeemed by virtuous institutions. This conception of human nature helps sustain a perspective rich in institutional restraints.

Strategies

The manner in which people make a living is central to their lives. Thompson *et al.* (1990) argue that needs and resources are socially-constructed, so that the constraints on behaviour are located in the perspectives, rather than in the needs and resources themselves. This leads to the conclusion that behaviour is never rational or irrational in itself; a particular strategy can only be evaluated in relation to a person's perspective. Strategies do what is most important; i.e. they uphold a person's perspective. Because the egalitarians perceive resources as being fixed and believe that people can do nothing about them, the only available strategy is to decrease their needs so as to ensure a non-negative overlap. If it is to be effective, such a need-reducing strategy would have to be followed by everyone. In perceiving nature as cornucopian, the individualists clearly have the scope to manage both needs and resources. Therefore they choose to manage needs and resources upward to the very limits of their skills. The hierarchists cannot do anything about their needs, so the only available strategy is to increase their resources so as to make sure that the overlap does not become negative. This approach is legitimated by a view of nature as bountiful but within accountable limits. For each of the perspectives, preferences regarding topics such as economic growth or risks can be derived in a similar manner.

Following Thompson *et al.* (1990) and Trisoglio *et al.* (1994) the cultural perspectives can be characterized by two dimensions: 1) how the world is seen (the totality of views of physical and human nature) and 2) management style (the totality of preferred strategies) (*Table 2.1*).

2.4. Cultural Perspective-based Uncertainty Analysis

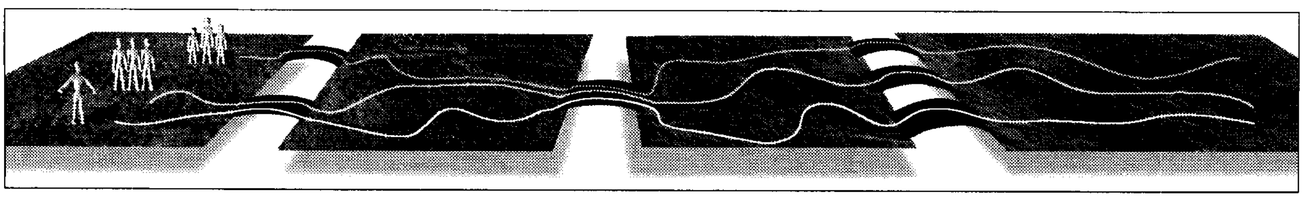
2.4.1. Alternative model routes

How can we operationalize the active perspectives, as characterized by world view and management style, to illuminate uncertainties in integrated assessment models? In this report we present the concept of alternative model routes. We use the extended metaphor of different walks through a landscape to clarify our concept.

A group of hikers embark on a walk from the same point in the landscape. They look at the landscape surrounding them, but interpret what they see in different ways, so that they will not all march off in the same direction. For example, if they see a mountain ahead of them, one will see it as a challenge and wants to climb it, while a companion prefers a route avoiding the mountain for fear of falling off. A third hiker would like to enjoy the panorama at the top, but thinks climbing is too risky, and thus follows established paths to ascend. At every juncture the walkers are obliged to choose how they will cross the landscape. When they start they cannot sum up the situation in advance, and they might encounter ravines or fast-flooding mountain brooks, which are too far away for them to see. When they arrive at such kinds of obstacle, they either prefer to turn back or to find a way to cope with the situation, for example by building a bridge over the brook. Thus the landscape might change due to their actions.
An example of such an action is building a campfire, since it will surely scorch the surface beneath it. The impacts of such an action may be unexpectedly great and perhaps irreversible: a spark from a campfire can start a forest-fire. Some of the walkers regard the risk of this occurring as being very low, others will first build trenches filled with water round the site of the campfire, and still others are anxious to avoid every risk that anything as destructive as a forest-fire might occur, and therefore abandon of the entire idea of a campfire. The landscape can also be changed by factors such as the weather (for example, rain can transform the chosen path into an impassable muddy track) and unpredictable events like earthquakes might also cause irreversible transformations and throw up unexpected obstacles. The walkers learn from their experience: and if, for example, they once erected their tent on a hill and experienced horrible problems when it rained, they later pay more attention to their choice of campsite. They thus start without much knowledge of the landscape itself nor of the dynamics within it, and similarly they do not understand either the impacts of their actions or of other pressures on the dynamics. Nevertheless, during their walk they learn how they can cope with various situations.

TARGETS can be seen as a "model landscape" in which endogenous and exogenous pressures on the dynamics result in certain impacts on the model landscape. Alternative model routes can be thought of as different "walks" through the TARGETS landscape (*Figure 2.4*). The alternative model routes reflect the interpretations of the active cultural perspectives; each adherent to a particular cultural perspective chooses at each "crossing" in the landscape the route which reflects its bias. That is why we call our concept perspective-based alternative model route, as a methodology which renders uncertainties due to subjective judgment and disagreement explicit. Examples of such uncertainties within the TARGETS model and perspective-based interpretations are shown in *Figure 2.5*. Within the population dynamics model, for instance, the relationship between social processes and the use of contraceptives is uncertain. *Figure 2.5* shows three alternative processes primarily determining the use of contraceptives: family planning programmes, human development or individual opportunities. Similarly, within the energy model the magnitude of the natural resources is exhaustively discussed: are the resources limited, scarce or abundant? Climate sensitivity, i.e. the equilibrium temperature increase in the case of a CO_2 doubling in the atmosphere , within the global cycles model is another example of an uncertain relationship.

Figure 2.4: Alternative routes



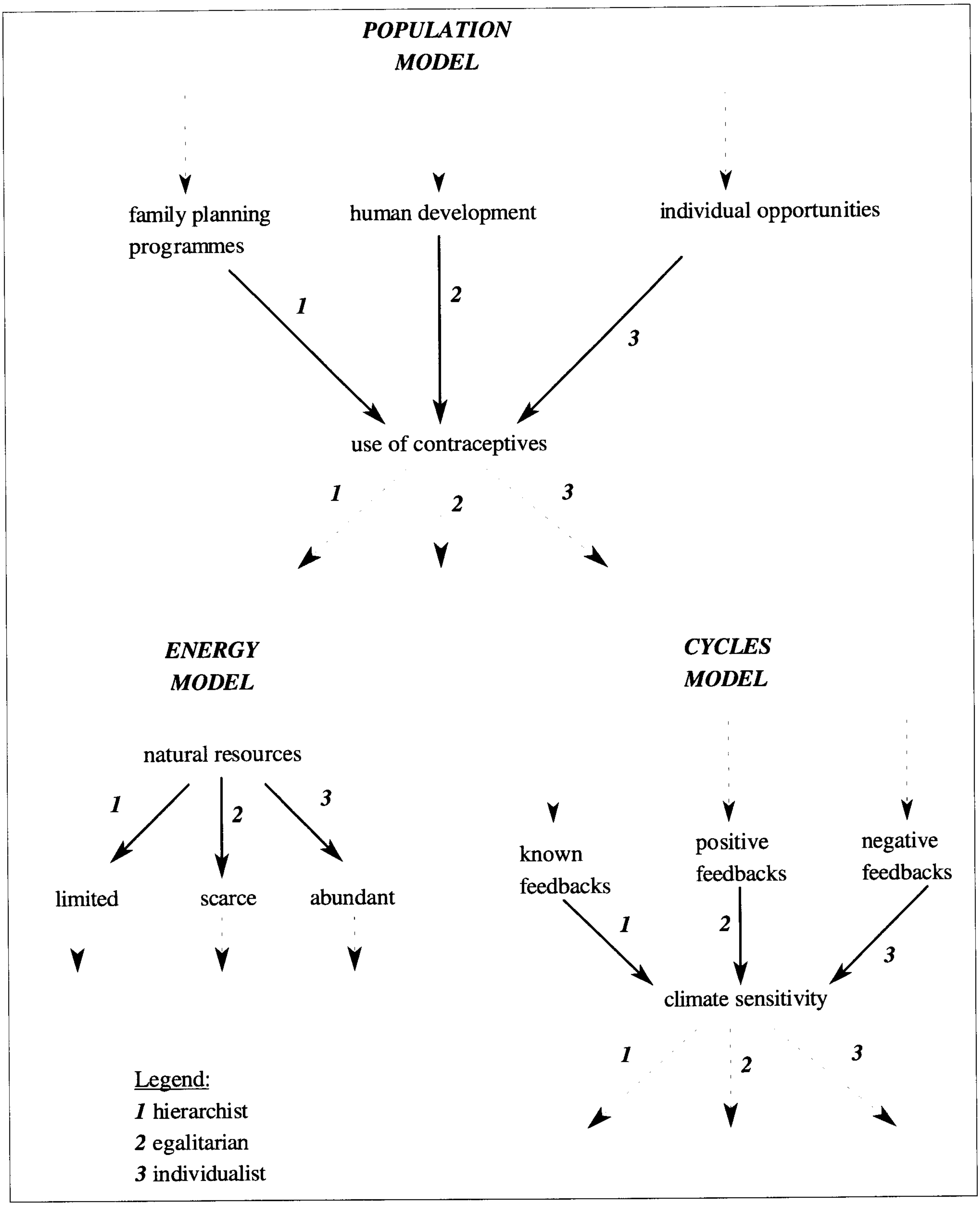


Figure 2.5: Examples of uncertainties and alternative routes

The alternative model routes provide consistent clusters of such crossings within the model. In other words, model routes are chains of motivated interpretations of the perspective-related uncertainties in the model, whereby the cultural perspectives determine the coherence of interpretation of the uncertainties. Thus, alternative model routes are "sub-models" in which the parts associated with subjective judgment and disagreement among experts are coloured by the bias and preferences of a certain perspective.

2.4.2. From uncertainty to risk

The distinction between world view and (associated) management style (see Subsection 2.3.2.) is reflected in the TARGETS model in the distinction between Pressure-State-Impact-system, in which the cause-effect chains are modelled, and Response-system, which signifies human response strategies. The world views associated with the different perspectives are used to establish alternative model routes in the Pressure-State-Impact system. The favoured management styles are used to develop different model routes in the Response system, which reflect different strategies.

The combination of each perspective's world view with its respective favoured strategy is used to assess the utopias (Trisoglio *et al.*, 1994). A utopia is a world in which they are in charge and in which their view of the world describes the real functioning of the human and environmental system (see *Figure 2.6.*). The dystopias (Trisoglio *et al.*, 1994) describe what would happen to the world if one's favoured strategy were to be applied while reality proved not to resemble the adopted world view. Dystopias also describe the opposite case, i.e. where one's favoured world view is adopted, but opposing strategies are applied (see *Figure 2.6.*). With respect to communicating the role of uncertainty to decision-makers the dystopias are most interesting. If we examine a column in *Figure 2.6.* we see that the dystopias indicate the risks of decision-making under uncertainty by showing which effects chosen strategies may have when the adopted world view fails to describe reality adequately. In other words, what would happen if events in the future taught decision-makers that their perspective-based interpretation of uncertainties turned out to be flawed? We would be able to analyse the dystopias in model terms by combining the world views, represented as alternative model routes in the Pressure-State-Impact system, with the management styles, represented as model routes in the Response system. Thanks to the analysis of risks in terms of utopias and dystopias, uncertainty is no longer a purely abstract theoretical concept, but a notion which can be usefully deployed by decision-makers while they are arriving at their decisions.

Figure 2.6: Matrix of perspectives

MANAGEMENT STYLE	WORLD VIEW: **egalitarian**	**hierarchist**	**individualist**
egalitarian	***utopia***	dystopia	dystopia
hierarchist	dystopia	***utopia***	dystopia
individualist	dystopia	dystopia	***utopia***

2.5. Methodology

2.5.1. Articulation of expert judgment and scientific controversies

A basic feature of our approach is that a continuous dialogue between modeller and analyst is required. The modeller is seen as an expert and as a source of information about the model, while the analyst is the critical generalist who provides help in articulating the perspective-related uncertainties. The interactive process is divided into two successive phases: in the first phase, examination of state-of-the-art knowledge in the field concerned takes place, and in the second, the model itself is analysed to enable attribution of uncertainties to model quantities and relationships with the aim of creating "accessories" for alternative model routes.

We examine the state-of-the-art knowledge using the distinction drawn by De Vries (1989, 1993) between weak and strong knowledge. Strong knowledge is based on empirical facts, and therefore not subject to dispute. Weak knowledge incorporates a high degree of uncertainty, which is why its status is discussed among experts.
Although there is no absolute and undisputed definition of such a difference in knowledge, the existence of such a distinction is acknowledged, both in philosophy (Popper, 1934; Kuhn, 1962; Lakatos, 1968) and in the experience of scientists themselves. The dichotomization into weak and strong knowledge is, therefore, no brand-new concept; here we are merely translating established philosophical ideas into notions which can be understood by modellers who may not be familiar with such concepts. We do not define what is weak and what is strong knowledge, but simply use the dichotomy as a concept to make modellers aware that there is a difference in knowledge. The consequence is that the modeller is not asked to categorize state-of-the-art knowledge in well-defined classes, but rather to accept that his own definition or intuition of weak and strong can be used to articulate weaknesses in the state-of-the-art knowledge. The weaknesses identified, which are in fact scientific controversies, are associated with perspective-related uncertainties by virtue of the subjective judgment involved and the evident disagreement among experts.

We must admit that such an identification and selection process is liable to be biased. Morgan and Henrion (1990) and Frey (1992) discuss three approaches used by people, and observed by psychologists, which may lead to bias in judgment:

1) *availability*: the probability that experts are biased towards outcomes they have recently observed or can easily imagine, as opposed to other possible outcomes which have not yet been observed in tests.
2) *representativeness*: experts may tend to assume that the behaviour they observe in a restricted set of data must be representative of the behaviour of the whole system.
3) *anchoring and adjustment:* experts may use a natural starting point (anchor) as the basis for making adjustments, and thus suffer from overconfidence, i.e. the expert's judgment reflects less uncertainty than it should.

Judgment may also be biased for motivational reasons: 1) the expert may wish to influence a subsequent decision in a certain way; 2) the expert may perceive that he will be evaluated on the basis of the outcome and might therefore tend to be conservative in the estimate; 3) the expert may be concerned to suppress uncertainty that he actually believes is present in order to appear knowledgeable or authoritative; and 4) the expert has taken a strong stand in the past and does not want to appear to weaken the force of an earlier statement by pointing to uncertainties that lend credence to alternative views (Frey, 1992).
In general, experts' judgments about uncertainties tend to improve when: 1) the expert is forced to consider how things could turn out differently than expected and 2) the expert is asked to list reasons for his opinion (Kenney and von Winterfeldt, 1991; Otway and von Winterfeldt, 1992; Frey, 1992). 'Perspective change' exercises, whereby the modeller is asked to think like a "devil's advocate", are used to stimulate the experts to think beyond established expectations and estimates, and thus force them to motivate their opinions. Imagination of adherents of each of the cultural perspectives as "wanderers" through the TARGETS landscape also forces the modeller to consider fundamentally different possibilities and probabilities thoroughly.

2.5.2. Model analysis

The parameters and variables in the submodel are classified as being empirical quantities, value variables/parameters, state variables, steering variables or auxiliary variables/parameters (see Subsection 2.1.3.). Where the Pressure-State-Impact system of the model is concerned, only empirical quantities and value variables/parameters can contain perspective-related uncertainties. In the Response-system

Table 2.2: Classification of degree

MAGNITUDE		qualitatively known	qualitatively unknown
quantitatively	known	degree = low	not applicable
quantitatively	unknown	degree = middle	degree = high

steering variables are the ones that matter. The empirical quantities identified, together with the value parameters/variables and steering variables are potentially affected by the uncertainties resulting from disagreement and subjective judgment.
Firstly, we use the classification of the model's variables and parameters to select those quantities which are the model's counterparts of the perspective-related uncertainties, which have been identified. Secondly, relationships related to those uncertainties are identified. These relations and quantities are the accessories which can be used to implement alternative model routes. The modeller "wanders" through a submodel of TARGETS which is part of the overall "landscape" and is asked to find the points at which "crossroads" have to be "signposted" to give other, perhaps less experienced, walkers the opportunity to choose between different routes. The modeller plays the role of "pathfinder" through a part of the landscape.

To summarize, expert judgment, together with analysis of the scientific controversies and model analysis results in an enumeration of the perspective-related uncertain quantities and relationships in a submodel. This set constitutes the potential set of accessories for the alternative model routes.

2.6. Selection criteria

As stated earlier, we aim at the articulation and illumination of the most important perspective-related uncertainties. Selection is necessary to arrive at a workable implementation of alternative model routes. Taking into account that integrated assessment models comprise various submodels, we strive for a selection of about 10 accessories per submodel. This Section examines various selection methods used to arrive at a set of significant model quantities and relationships per submodel. The selection heuristic may also be used in a later phase to determine which uncertainties are the most important in the integrated assessment model as a whole.

2.6.1. Ranking the uncertainties

In order to make a selection, the uncertainties, which have been identified, are ranked. As indicators for the importance of a specific uncertainty the following criteria are used: magnitude, degree and time-variability. The ranking of importance will be used to prioritise those uncertainties which cannot be left out of the analysis. This ranking enables us to make a selection.

Magnitude

Magnitude denotes the relative contribution of the uncertainty of a specific quantity or relationship to the overall uncertainty within a submodel. Expert judgments are used to classify the magnitude qualitatively in one of three classes (small, middle and large) and to indicate whether quantitative estimations of the magnitude are available.

Degree

The criterion of degree denotes the absolute uncertainty of specific quantities and relationships. Using the characteristics of the magnitude, we classify the degree as low, middle or high. Considering the magnitude three eventualities are possible: 1) the magnitude is known neither qualitatively nor quantitatively; 2) the magnitude is known qualitatively, but not quantitatively; and 3) the magnitude is known in both a qualitative and quantitative sense. These combinations are used to classify the degree of uncertainty (*Table 2.2*).

Time-variability

According to the results of (new) scientific research specific uncertainties could shrink, but could also

Table 2.3. Classification of importance

magnitude	**degree**	**time-variability**	**importance**
large	high	high/ middle/ low	high
large	middle	high/ middle	high
large	low	high	high
middle	high	high/ middle	high
middle	middle	middle	high
large	middle	low	middle
large	low	middle/ low	middle
middle	high	high/ middle/ low	middle
middle	middle	middle	middle
small	high	high/ middle	middle
middle	middle/ low	low	low
small	high	low	low
small	middle	high/ middle/ low	low
small	low	high/ middle/ low	low

grow in stature (see for examples: Henrion and Fischhoff, 1986; Morgan and Henrion, 1990; Shlakhter and Kammen, 1992; Dowlatabadi and Morgan, 1993; Den Elzen, 1993). Seeing contemporary uncertainties in historical perspective reveals whether the rate of uncertainty is increasing or decreasing. The course of the historical debate is used to classify to what extent the estimates of the uncertainties have varied in time in order to yield an indication of a probable future shift in the estimates.

Importance

The uncertainties are now ranked by determining the importance of the uncertainty, using, in order of priority, the indices magnitude, degree and time-variability. We distinguish three classes: high, middle and low importance. Each class consists of 9 combinations of magnitude, degree and time-variability (*Table 2.3*).

2.6.2. Sensitivity and traditional uncertainty analysis as selection heuristic

In model development, sensitivity and uncertainty analysis should be regarded as essential in analysing the model to gain insight into the reliability of models (Janssen *et al.*, 1990). We adopt the definitions in Janssen *et al.* (1990):

> sensitivity analysis: study of the influence of variations in model parameters and initial values on model outcomes. Sensitivity analysis is notably important in situations in which these quantities cannot be determined with any degree of confidence.
>
> uncertainty analysis: study of the uncertain aspects of a model and the influence of these uncertainties on model outcomes. Uncertainty analysis is notably important in situations in which information is of poor quality and/or situations which are inherently uncertain. (Janssen *et al.*, 1990)

Both sensitivity analysis and traditional uncertainty analyses, such as Monte Carlo/Latin Hypercube Sampling, will be carried out as an essential step in the development of TARGETS (Rotmans *et al.*, 1994). The method of uncertainty analysis as described in the present report can be seen as complementary to such traditional uncertainty analysis techniques, as described by Janssen *et al.* (1990). We propose to use sensitivity and traditional uncertainty analysis as screening devices to provide a further selection of potential accessories for alternative model routes. Together with the expertise of the modeller the screening devices make it possible to restrict the list of potential accessories to manageable proportions.

The ranking of the uncertainties and the proposed selection heuristic, when iteratively employed, provide sufficient criteria to slim down the list of accessories to a workable set of variables, parameters and relationships per submodel.

2.7. Implementation

When accessories have been selected, we proceed to describe the interpretations of the different cultural perspectives as accurately as possible on the basis of the general descriptions provided by Thompson *et al.* (1990) (see Section 2.3.2.). Such a translation exercise is not free of subjectivity. The descriptions will therefore be discussed with cultural theorists. To return to our extended metaphor, the modeller and the analyst wander through the landscape on successive walks during which they in turn adopt the egalitarian, individualist and hierarchist world view. For the benefit of the less experienced walker, they erect signposts in the landscape to indicate which routes certainly lead to an end. The inexperienced walker can choose to follow one of these routes to explore the landscape, instead of blindly hoping to stumble across a suitable path.

"Erecting signposts" is equivalent to providing mathematical translations of the world views and management styles in order to implement perspective-based alternative routes in the model. In the case of parameters this means that alternative values need to be determined. In the initial implementation, this will be done simply by changing parameter values. When seeking a more sophisticated implementation, we would consider of using the concept of 'fuzzy logic' to create an option in which parameter values need not be, or can not be, determined with any precision. If the crossings are located in empirical quantities, following Morgan and Henrion (1990), we can use subjective probability distributions (see, for example: Morgan and Keith, 1994). In the case of relationships, functional forms need to be reformulated. In the simplest form, this means either changing the function (for example by making it exponential instead of parabolic), or deleting, adding or changing the function's arguments. In a more sophisticated procedure, reformulation can be performed, for example, by introducing non-linearities or concepts from complex adaptive systems.
The alternative model routes need to be calibrated, i.e. the resulting trends have to approximate what we regard historically as being certain. The methodology as sketched above is summarized in a flow chart (*Figure 2.7.*).

In this Chapter we have outlined a methodology which enables the alternative model routes to be incorporated in models. In the next Chapters, case-studies for the fertility submodel and the climate part of the global cycles submodel of TARGETS will be described to assess the usefulness and limitations of our cultural perspective-based uncertainty analysis. These two models are selected as examples since the former is a model with roots in the social sciences and the latter a model with its origins in the natural sciences. This enables us to evaluate the usefulness of our approach towards both socioeconomic and scientific uncertainties.
The fertility model has been selected for reasons of availability of documentation (it is already fully documented (Van Vianen *et al.*, 1994)) and for the sake of its simplicity. But above all, the current international policy debates, as conducted at the high-profile international Conference on Population and Development in Cairo (September 1994), demonstrate the importance of the role which socioeconomic uncertainties play in decision-making.
The climate part of the global cycles model has been selected, because the scientific uncertainties in the global climate research are extremely significant and the subject of serious discussion both in the scientific and the policy-making communities.

The translation and quantification of the cultural perspectives onto the fertility submodel and the climate part of the cycles submodel will be reviewed by cultural theorists and demographic and climate experts in the second quarter of 1995. Such review can help to improve the presented alternative model routes, and thereby improving the uncertainty analysis and scenario development.

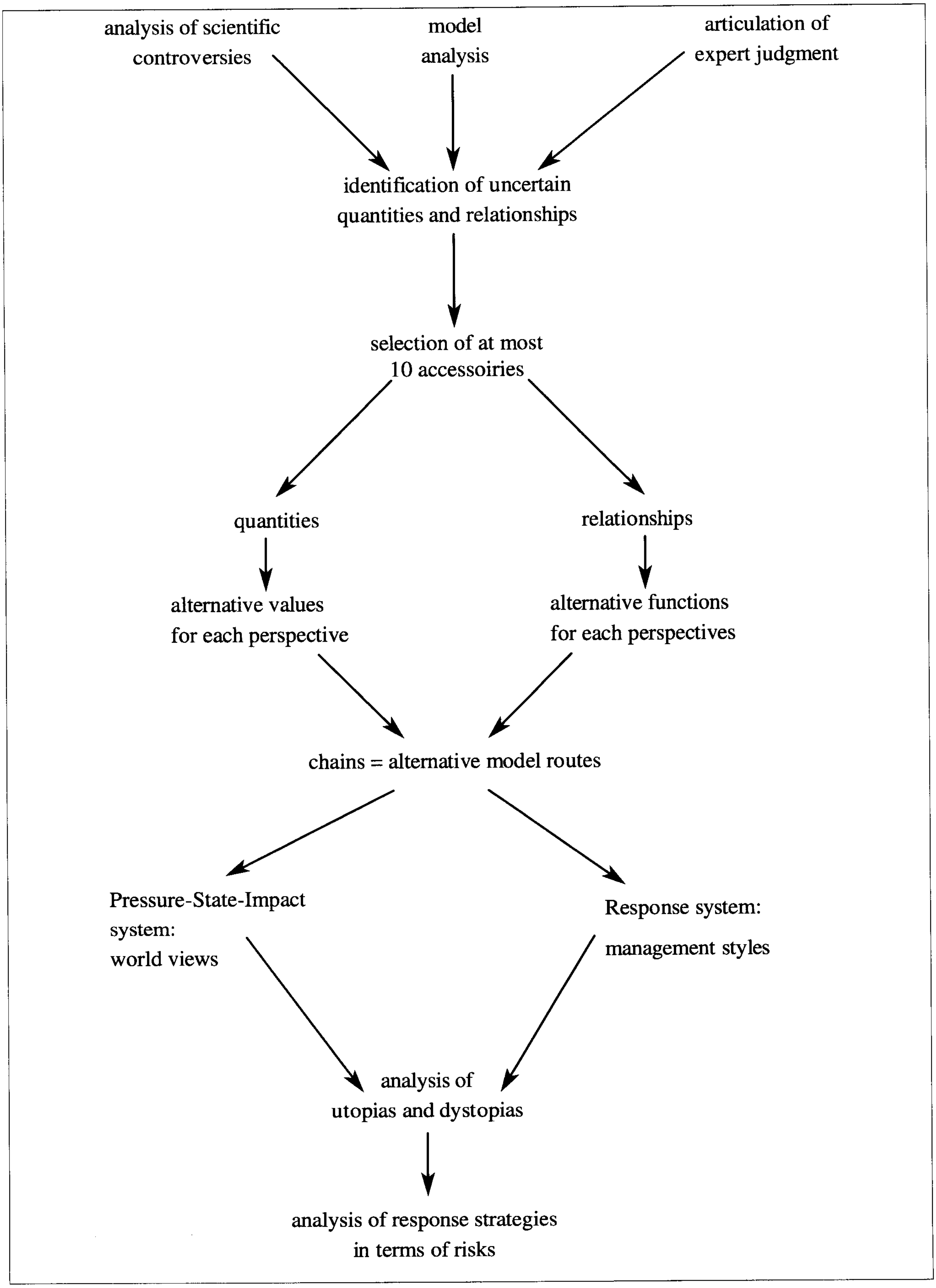


Figure 2.7: Flow chart of methodology of perspective-based uncertainty analysis

3. ALTERNATIVE MODEL ROUTES: *CASE STUDY BASED ON THE FERTILITY MODEL*

3.1. Introduction

The population issue has become the subject of a furious intellectual battle both in the scientific and the policy-making communities. Humanity is likely to keep growing in numbers, as everyone agrees, and such growth might have grave consequences. The controversy concentrates on the assessment and evaluation of those consequences. The main points of view in this debate are discussed here, in order to articulate the perspective-related uncertainties concerning human fertility. Having reviewed the literature and following discussions within the demographic research community (e.g. Amsterdam, November 1993 (Van den Brekel *et al.*, 1993), Ede, August 1994 (Bilderbeek *et al.*, 1994; Platform Cairo, 1994), Brussels, October 1994) and taking cognisance of the cooperative study conducted with the Population Research Centre of the University of Groningen (Van Vianen *et al.*, 1994) the main controversies concerning population growth and fertility change are described.

3.2. State-of-the-art

We now propose to address ethical, demographic and policy controversies in turn.

3.2.1. *Ethical controversy: the controversial character of the population issue*

One of the main controversies pertaining to population growth is: whether the explosive population growth is a problem and if so, is it a problem in itself or is it a problem only by virtue of the burdens it imposes on the environment and the human society? Concomitant with this question is the issue of whether population growth is simply a problem of numbers, i.e. exclusively an issue for the developing countries, or is it a combination of population numbers and an increasingly materialistic lifestyle, i.e. an issue for both the developed and the developing countries? As Platform Cairo (Bilderbeek *et al.*, 1994) summarized the dilemma 'Less people or less desires?'.

Population growth is a problem of numbers

According to this view, the natural level of a population is an equilibrium between birth and death rates. In this Malthusian way of thinking, every vigorous growth in population will eventually lead to disaster. We are now witnessing a tremendous imbalance causing an explosive population growth. Growth that continues indefinitely is impossible, mainly due to the limits to the planet's capacity to produce food (i.e. biological limits), and therefore, world population needs to be stabilized. It is by no means clear, however, what population level should be the absolute limit. Nevertheless, adherents to this view seem to agree that the growth rate needs to be levelled off as soon as possible.

According to this view, population growth is a problem of numbers, and in view of the high rates of fertility in developing countries, population growth is exclusively an issue for them. In a historical overview of the points of view adopted towards the population issue, Mann (1994) characterizes those who stand at this pole in the debate as being 'pessimistic Cassandras'. These prophets of doom, who tend to be biologists, regard each new birth as the arrival on the planet of another hungry mouth to feed. According to Mann, prominent historical exponents of this point of view include Malthus (1789) and Ehrlich (1968) and more recently Brown and Kane (1994):

> 'After nearly four decades of unprecedented expansion in both land-based and oceanic food supplies, the world is experiencing a massive loss of momentum. (..) After expanding at 3 percent a year from 1950 to 1984, the growth in grain production has slowed abruptly (..). As a result, grain production per person fell by 12 percent during this time. (..) In 1989, the fish catch reached 100 million tons. After achieving this level (..) the catch has fluctuated between 96 million and 98 million tons. As a result, the 1993 per capita seafood catch was 9 percent below that of 1988.' (Brown and Kane, 1994)

Based on the evaluation of such trends in food production in relation to population growth they conclude that:

> 'it is difficult to see how an acceptable balance between food and people can be achieved without a broad-based reduction in population growth'. (Brown and Kane, 1994)

Population growth is a socio-economic and environmental problem

According to this view, population growth was not in itself a problem, but became a problem because the explosive population growth caused and will go on causing problems such as: poverty, hunger, insecurity, environmental pollution and resource depletion. In other words the tolerable limit of population levels is coupled to ecological and socioeconomic criteria. The maximum size of the world's population is thus no more than a relative notion. Any further catastrophe will not be result of mass starvation, but rather be due to socioeconomic breakdowns (see for example King and Elliot, 1994; Bonneux, 1994) and ecological crises (see for example Meadows (1974); and as cited in Mann (1994); Keyfitz, (1993)). The outbreak of wars, as in Ruanda (Bonneux, 1994), are examples of such possible socioeconomic disasters associated with population numbers. Facts as land degradation[1], environmental pollution, ozone depletion and global climate change highlight the evident ecological consequences of overpopulation and the resulting increase in human activities.
In view of the present state of the world, in a human and environmental sense, securing an endurable future inevitably requires the curbing of the current population growth. Stabilization of numbers is not enough: this should be accompanied by a change in consumption and production patterns, especially in the developed countries in order to decrease the human-induced pressures on society and the environment. A recent statement of Ehrlich (in IIED, 1994) stresses the interrelationship between the significance of population levels and relative consumption patterns:

> 'The United States poses the most serious threat to all human life support systems. It has a gigantic population, more than a quarter of a billion people. Americans are superconsumers, and use inefficient technologies to feed their appetites. Each on average, uses 11 KW of energy, (..) over one hundred times as much as the average Bangladeshi. Clearly, achieving an average family size of 1.5 children in the United States would benefit the world much more than a similar success in Bangladesh.'

This point of view is also reflected in statements such as: 'The North must reduce its abusive consumption pattern; and the South, with the help of the North, must secure the conditions necessary to reduce its exponential population growth' (IIED, 1994) and likewise: 'For the survival of mankind on Earth, the number of 10 or 12 billion of people may be less important than the way they live.' (Beets, 1995).

Population growth is no problem

Outside the demographic research community, there are those who adhere to the idea that population growth is not a catastrophic threat. Humanity may face problems but has good prospects of coming out well in the end. Mann (1994) characterizes those who stand at this pole of the debate as 'relentlessly optimistic Pollyannas'. These Pollyannas, who tend to be economists, point out that along with each new mouth comes a new pair of hands. This creates new opportunities, since the result is more consumers and more economic and political power. A high fertility rate signifies a healthy and powerful community (did not the Bible, for example, urge humanity to be fruitful and multiply). Thus, according to this view high fertility rates are not a problem: "It is up to God". It is impossible to breed too much, because God would always provide (Martin Luther as paraphrased in Mann (1994)). Another historical exponent of the Pollyanna position is Condorcet (1794). He believed that technology could solve the problem. 'When hunger threatens humanity', he wrote, 'new instruments, machines and looms' will continue to appear, and 'a very small amount of ground will be able to produce a great quantity of supplies' (quoted in Mann, 1994). Nowadays, modern agricultural methods are being applied in the developing countries, and, moreover, genetic engineering is seen as a route to the almost limitless growth of agricultural productivity. Pollyannas point to the fact that, notwithstanding the population growth, per capita global food production actually rose more than 10 percent from 1968 to 1990 and that the number of chronically malnourished people fell by more than 16 percent (FAO, 1990). They also refer to the fact that salmon have been reintroduced to England's Thames River, that the white-tailed deer, almost extinct in 1900, plague New England gardens and that the air quality in Tokyo has improved remarkably (Mann, 1994). If all this occurred during a population boom, why the belief that 'overpopulation' will lead to a human and/or ecological catastrophe? Referring to the observed propensity for families in prosperous societies to have fewer children, Pollyannas maintain that continued economic and technological growth

[1] Since 1945 human activities have rendered 17 percent of the world's land infertile, over and above barren areas such as Antarctica and the Gobi desert (International Soil Reference and Information Centre in the Netherlands (Mann, 1994)).

can both feed thousands of millions of people and increase affluence in the world sufficiently to put an end to the population boom (Mann, 1994). According to this point of view, human-induced stabilization of population growth would simply be redundant.

3.2.2. Demographic controversy: the macro versus the micro view

The demographic data do not allow us to derive an unambiguous understanding of the factors that trigger structural changes in fertility behaviour, i.e. the so-called demographic transition. 'This is obviously an important subject which requires further research' (Rodriguez and Avarena, 1991). The core of the demographic controversy is, therefore, which processes constitute changes in the fertility behaviour and patterns. The central question is 'at which level of society fertility behaviour (can be) changes(/d) and at what level this change should and can be managed'. In short: the macro versus the micro view (Van den Brekel *et al.*, 1993).

Micro processes determine fertility behaviour

Those who adopt the micro view hold that if individual couples prefer a small family, they will find the means by which to control their individual fertility. Adherents to this point of view refer to France, where total fertility was already at low levels when modern contraception methods were not yet available and where family planning was condemned by public spokesmen.

The totality of individuals' choices and resulting behaviour constitutes the overall fertility pattern. Individual choices are influenced by social norms and attitudes (Fishbein and Ajzen, 1975), which are determined by individual characteristics as age, education level and income status. Examples of changing individual preferences due to a higher level of prosperity and income are the ways in which children are seen as a hindrance: because of the high costs of raising a child, because children might hamper self-development (for example in the form of a professional career for both man and wife) and because children might decrease the opportunities to enjoy life (for example going on holiday quite often). Another change on the micro level which affects fertility is that a higher level of education and a stronger position of women ('empowerment', (UNDP, 1994)) induces a wish for a smaller family. Due to a social norm in which children are seen as individuals who deserve a lot of personal attention, individual couples may prefer smaller families, whereas in a social envrionment in which children are perceived as blessings, the couple's preferred size for a family might be different. To summarize, according to this view, global (macro) fertility change is the result of bottom-up changes in fertility behaviour and cannot be altered by top-down policy measures.

Macro processes determine fertility behaviour

The macro approach holds that the fertility behaviour exhibited by couples is primarily determined by the attitude of spokespersons, such as the State and the Church, towards fertility issues. People at the (regional or global) governing level take general and long-term dimensions into account to ensure the well-being of the whole. In contrast, individual couples do not take important regional or global dimensions into consideration. Others would have made them aware of the necessity before they would change their fertility behaviour. Where population growth is considered to be a problem, whether for macro-economic or environmental reasons or both, a government (or other steering actor) can and should intervene in the individuals' fertility behaviour in order to control the overall population growth. According to this view, trends towards smaller families only occur if top-down initiatives are involved. The macro view can therefore be characterized as a top-down approach.

3.2.3. Policy controversy: how to control fertility?

Where the explosive growth in population is considered to be a problem, the question arises as to which policy measures can be applied to control fertility. Regarding possible policies three competing views are defended: 1) family planning, 2) modernisation and 3) a do-nothing policy. Concerning policy measures two controversies are to be distinguished: 1) 'how can and should a steering actor attempt to control population growth?' (the family planning versus modernisation gap) and 2) legalisation vis-à-vis prohibition of abortion.

3.2.3.1. The family planning versus modernisation gap

Family planning

The 'family planning' view, has it that high fertility is predominantly a consequence of inaccessibility or prohibitive costs of contraceptive services. If access to contraceptives improved and costs were lower, fertility would decline. As Robey *et al.* (1992) conclude "although development and social change create conditions that encourage smaller family size, contraceptives are the best contraceptive". Therefore, the emphasis is on family planning programmes, whereby education and mass communication might be considered as supporting means.

Modernisation

According to the second view, to which sociologists and economists in particular adhere, socio-economic development (or 'human development' as defined by the UNDP (1994)) is believed to be the best contraceptive. If the socio-economic status, the level of education and the health status (measured by life-expectancy) of individuals and of society as a whole were higher, the demand for children would change. Declines in fertility are brought about by changes in the demand for children. In this view, family planning programmes only have a minor effect on changes in reproductive behaviour. As Becker (1991) states "improvements in birth control methods are mainly an induced response to other decreases in the demand for children rather than an important cause of the decreased demand". Pritchett (1994) claims that high fertility reflects desired births and that couples are largely able to achieve their fertility targets. He concludes that "men's and women's fertility choices, which are conditioned and constrained by the social, educational, cultural and economic conditions they face, are the primary determinants of actual fertility". Moreover, policies which improve the status of women -better education, labour participation and empowerment- are believed to be most important in achieving a reduction in fertility (Pritchett, 1994). Therefore, the best way to rein in fertility behaviour is to improve the socioeconomic status, especially of women, in countries and regions with high fertility levels.

A do-nothing policy

Where fertility is not perceived as a problem, no explicit population policy is necessary. This option is also advocated when fertility is perceived as a process which may not be influenced by humans. On religious, cultural and/or ethical grounds, developments such as, for example, the use of contraceptives and the 'empowerment' of women are considered to be undesirable. Even where population growth is actually perceived as a problem, fertility decline should be effected by traditional means, such as abstinence, which are culturally and ethically acceptable and sanctioned by religion.

3.2.3.2. Prohibition versus legalisation of abortion

The issue of legislation concerning abortion is still one of the most debated issues concerning population policy, as for example the course of the Conference on Population and Development in Cairo showed. The poles of the debate are discussed below.

Prohibition of abortion

On religious, cultural and ethical grounds, abortion is perceived as reprehensible, either because the right of the unborn child to survive is violated (abortion is perceived as murder), or because it is seen as an unacceptable and harmful interference with women's bodies. Abortion should therefore be prohibited, and indeed, in many countries abortion is actually punishable under penal law (Cleland and Scott, 1987).

Legalisation of abortion

Women's rights organizations in particular argue vigorously in favour of the legalisation of abortion as ultimate means of fertility control. According to this view, couples should enjoy a free choice in deciding whether they practise abortion or not. If they choose to induce abortion, they should have access to safe facilities. In the former communist countries of Eastern Europe in particular, where abortion was legalized, abortion is actively used as means of last resort in fertility control. In the former USSR for example, an average woman terminates as many as five pregnancies during her reproductive period (Van Vianen *et al.*, 1994).

3.3. Uncertainties in the TARGETS fertility model

The fertility model, as extensively described in Van Vianen *et al.* (1994), is part of the integrated population and health model of TARGETS (Rotmans *et al.*, 1994; Niessen *et al.*, 1993) (see also Chapter 1). This Section describes the main features of the fertility submodel (*Figure 3.1*) in order to enable the perspective-related uncertainties in the model to be localized.

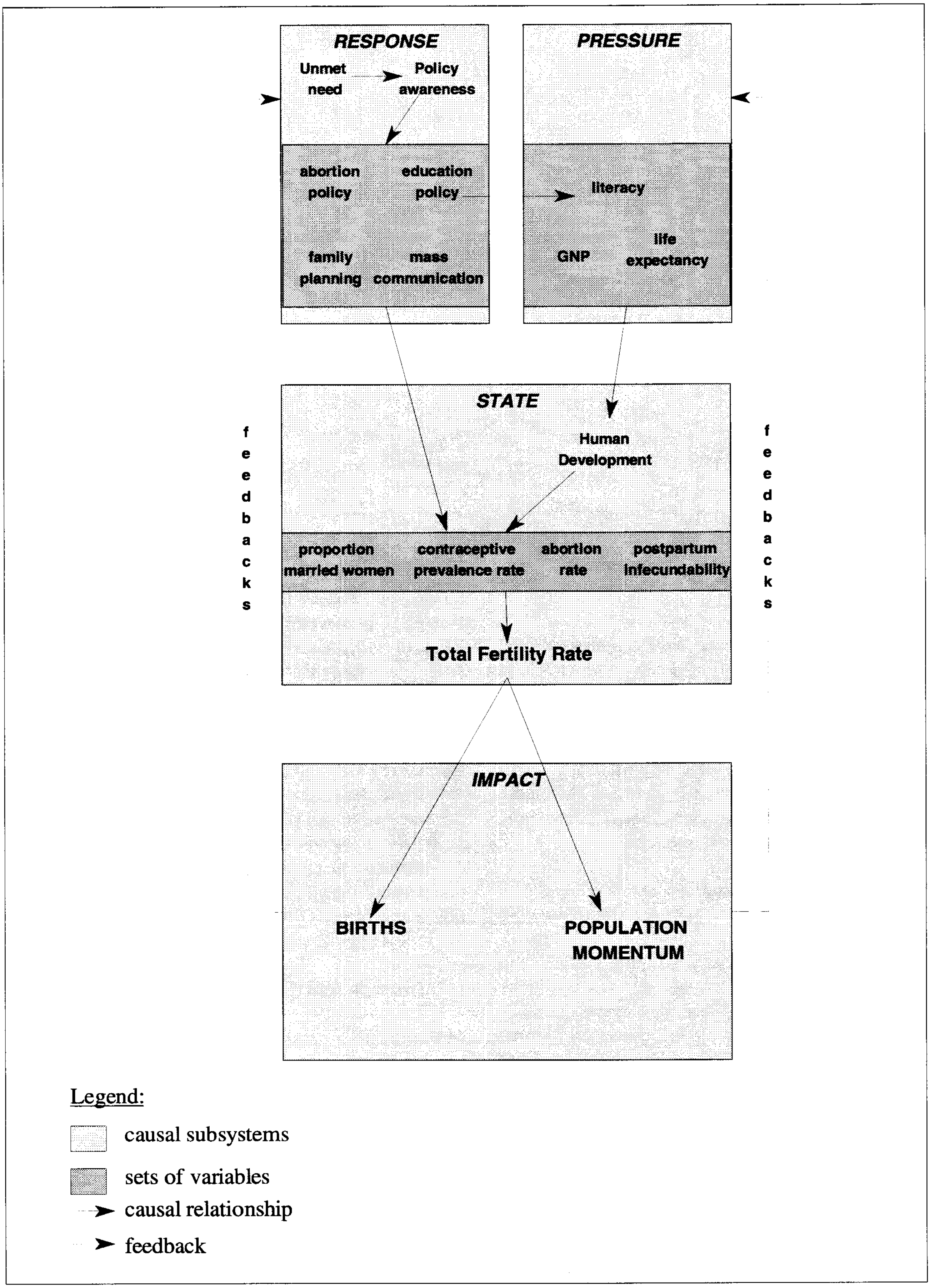


Figure 3.1: P-S-I-R representation of fertility submodel

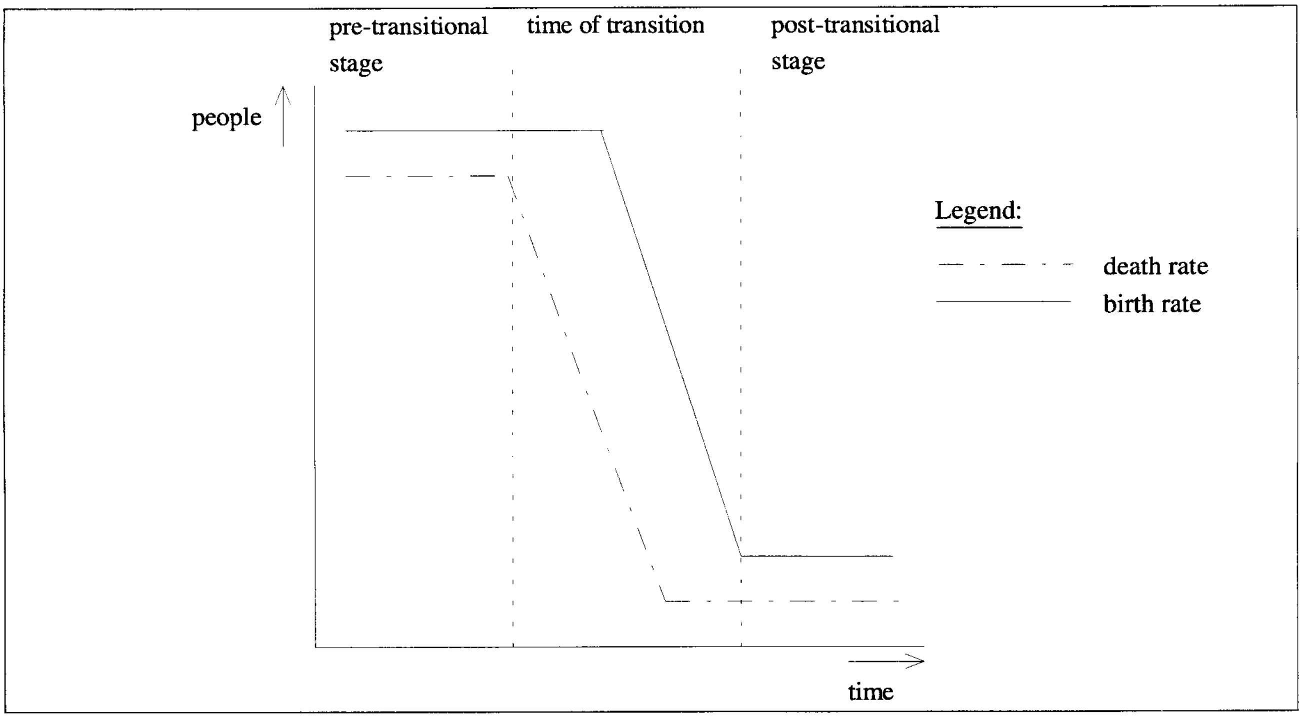


Figure 3.2: Schematic representation of demographic transition

3.3.1. Model description

Within the TARGETS model, an integrated systems approach (Rotmans, 1990; Rotmans *et al.*, 1994) is adopted. When applied to fertility issues, the integrated systems approach takes account of the various factors that affect fertility directly or indirectly, as well as monitoring how these factors change over time and how they interact. Cause-effect chains are aggregated, as appropriate, into a Pressure, a State, an Impact and a Response subsystem.

The ***Pressure*** system describes the driving forces behind fertility changes and comprises the following variables: life-expectancy, female literacy, socio-economic status and current population growth. Van Vianen *et al.* (1994) argued that the driving forces are embedded in the whole complex process of modernisation. They therefore elected to use the Human Development Index (HDI), as defined by UNDP (1994), as their indicator of the level of socioeconomic development. HDI incorporates life expectancy, literacy and the socioeconomic status (measured by reference to the gross world product (GWP)). Life expectancy and GWP are derived from other modules of TARGETS (namely: health and energy/economy). Population growth is modelled as a feedback from the Impact system. Female literacy levels are incorporated within the fertility model. It fell beyond the scope of the fertility model study to model the process of education. Having accepted that there is a correlation between literacy and the level of human development, Van Vianen *et al.* (1994) assumed that an increase in the level of development implies progress in establishing or improving the education system. The effects of such structural improvements are assumed to manifest themselves 10 years after their introduction. Additional measures in the field of education which are carried out within the scope of family planning policy (and incorporated in the Response system), are assumed to manifest themselves after 2 years, due to the time needed to implement such specific policy measures. These assumptions are expressed in the following formula:

$$female\_lit = HDI\_del^{\,(1 - education\_pol\_del)} \qquad (3.1)$$

where: HDI_del = the human development index with a delay of 10 years
education_pol_del = the policy effort to improve education (scale 0-1) with a delay of two years

The ***State*** system describes the processes constituting the fertility transition. Fertility and mortality transition are the two dimensions of the so-called 'demographic transition' (Notestein, 1945; Davis, 1945) (see *Figure 3.2*). The demographic transition is presented as tripartite. In the *pretransitional stage*, both mortality and fertility are high and approximately cancel each other out, thereby generating extremely slow population growth. Mortality is more or less irregular and trends are interrupted by 'mortality crises'. In the second stage, the *time of transition*, mortality starts to fall while fertility remains high, generating a period of rapid population growth until, after a time-lag, fertility also starts to decline. In the third and final stage, the *post-transitional stage*, populations exhibit low, and approximately equal, levels of both mortality and fertility and little or no population growth in the long-run. During this stage, however, the fertility trend is more or less irregular since it incorporates 'baby booms' and 'slumps', the mortality rate being more or less constant.

Within the State system, both the total fertility, i.e. the number of children per woman, and wanted total fertility, i.e. the number of children a couple desires, are calculated. Total fertility is always well below the biological maximum of about 15.3 children per woman (Bongaarts, 1982) because of fertility-inhibiting factors. In demographic research, a distinction is drawn between two types of variables that influence fertility: 1) *intermediate variables* (Davis and Blake, 1956) or *proximate determinants* (Bongaarts and Potter, 1983), i.e. biological and behavioural factors which affect fertility directly, and 2) *indirect variables*, i.e. social, economic and environmental pressures which affect fertility through the intermediate variables. Four proximate determinants stand out as being the most important (Bongaarts and Potter, 1983): marriage, use of contraceptive methods, induced abortion and postpartum infecundability (i.e. infertility after delivery). Bongaarts and Potter (1983) developed a model which links these four proximate determinants, a model which forms the core of the State system, and is expressed as follows:

$$TFR = C_m \bullet C_c \bullet C_a \bullet C_i \bullet TF \qquad (3.2)$$

where TFR = the total number of children per women
C_m = index of proportion of women in marriage (equals 1 if all women of reproductive age are married and 0 in absence of marriage)
C_c = index of contraception (equals 1 in the absence of contraception and 0 if all fecund women use 100% effective contraception)
C_a = index of abortion (equals 1 in the absence of induced abortion and 0 if all pregnancies are aborted)
C_i = index of postpartum infecundability (equals 1 in the absence of lactation and postpartum abstinence and 0 if infecundability is permanent)
TF = the biological maximum of 15.3 children per woman

In the model, each of the proximate determinants is determined by deploying a range of indirect variables, variables which are derived from the Pressure and the Response systems:

$$C_m = Ult_m * \frac{40 - Avg_m}{25} \qquad (3.3)$$

where Ult_m = proportion of women who ultimately marry, which is estimated as 0.95 (Van Vianen *et al.*, 1994)
Avg_m = mean age on wedding day, which depends on the value of HDI
40 = age at last childbirth before menopause
25 = duration of reproductive interval (15-40 years)
HDI = human development index

$$C_c = 1 - 1.08 * CPR * \sum_{i=1}^{4} s_i * e_i \qquad (3.4)$$

where e_i = the average use-effectiveness of contraception method i (sterilization, IUDs, the pill, others), which partly depends on the value of HDI
s_i = the prevalence of method i in contraception
1.08 = correction factor for involuntary infertility (Bongaarts and Potter, 1983)
CPR = contraceptive prevalence rate, i.e. the proportion of married women currently using contraception. Determinants of CPR are awareness_ind, i.e. the awareness of a couple in controlling their fertility, and the diffusion_rate, i.e. the rate of adoption of contraception, which is estimated as 0.06 (i.e. 6% per year, based on Rodriguez and Avarena (1991)). Awareness_ind is determined by the PES, i.e. the family planning effort (PES), HDI and masscomm (masscommunication directed to fertility control).

$$Ci = 1 - 0.51 \bullet e^{-2.21 \bullet HDI} \qquad (3.5)$$

where HDI = Human Development Index

$$C_a = \frac{1}{1 + b * AR} \qquad (3.6)$$

where b = ratio of reproductive time lost per abortion to the length of the interval in the absence of contraception

AR = the number of induced abortions of live births, which depends on CPR (see equation (3.5))

Wanted total fertility is the number of children a couple ideally desires. Following Bongaarts (1992) it is modelled as being determined by human development and family planning, accounting for significant delays in effect of 5 and 20 years, respectively.

$$WTFR = 5.3 - 6.1 * HDI_{del} - 1.2 * PES_{del} \quad (3.7)$$

where HDI_{del} = the delayed effect of progress in human development

PES_{del} = the delayed effect of family planning campaigns

The ***Impact*** system describes the immediate and long-term consequences of fertility change. The immediate impact is the number of births which, together with the number of deaths derived from the health module, generates the actual population dynamics.

$$Births = Pop^f(15-45) * GFR \quad (3.8)$$

where GFR = the average number of children per woman per year, which is an age-specific derivationof the total fertility (TFR)

$Pop^f(15\text{-}45)$ = the female population aged between 15 and 45 years

The long-term outcome is expressed as the population momentum (Bongaarts, 1994), which estimates the factor by which current population will continue to grow before reaching a standstill, in which case fertility is immediately reduced to the replacement level of 2.1 children per woman. The population momentum depends on the total fertility and the life-expectancy (output of the health module).

The ***Response*** system incorporates the responses to feedbacks from the impact system. In the fertility model, unmet need and policy awareness are feedback mechanisms which influence the priority given to population policy. Unmet need represents the number of children born who were not, in fact, planned:

$$\text{unmet\_need} = \textit{if } WCPR > CPR \textit{ then } WCPR - CPR \textit{ otherwise } 0 \quad (3.9)$$

where WCPR = wanted contraceptive prevalence rate, which depends on the wanted total fertility (WTFR)

CPR = contraceptive prevalence rate

Policy awareness signifies the awareness of a population problem on a macro level, which is induced by the mean discrepancy between the rates of population growth and economic growth in the last ten years. Both unmet need and policy awareness determine (with time delays) the priority for population policy:

$$\text{priority} = \text{unmet\_need}_{del} - \text{awareness}_{del} \quad (3.10)$$

where unmet_need_{del} = the influence of unmet need with a delay of 10 years (bottom-up influence)

awareness_{del} = the influence of policy_awareness with a delay of 5 years (top-down influence)

The policy priority becomes manifest in four policy options: abortion policy, education policy, family planning resource allocation and mass communication. The four policy options are represented by steering (or decision) variables, which can be changed by the user. In this way, the proximate determinants of fertility can be influenced exogenously. A delay of two years between policy measures and manifestations of actual effects, due to the time needed for implementation, is taken into account.

3.3.2. Accessories for alternative model routes

In order to accommodate perspective-related uncertainties as described in the previous section, uncertain relationships and quantities in the TARGETS-fertility model need to be selected to function as accessories for alternative model routes. The core of the model, which is based on Bongaarts' works, i.e. the four proximate determinants and their compound effect on the total fertility rate, is not open to discussion, and can, therefore, be considered as the strong (knowledge) component of the fertility model. In order to select the perspective-related uncertainties in the fertility model, the weak quantities and relationships, which to a greater or lesser extent are affected by the four controversies (Section 3.1), need to be identified. *Table 3.1.* summarizes the results of the model analysis. *Figure 3.3* indicates where the weak (knowledge) components are located in the fertility model.

Ranking uncertainties according to their importance

The perspective-related uncertainties are characterized and ranked using the indicators magnitude,

Table 3.1 Uncertain quantities and relationships in the fertility model

	Pressure-State-Impact			Response		
controversy	***quantity***	***type***	***relationship***	***quantity***	***type***	***relationship***
ethical controversy						policy-awareness (indicating seriousness of population issue, scale 0-1)
						priority (level of political and financial efforts devoted to fertility decline, scale 0-1)
demographic controversy	diffusion_rate (the rate of adoption of contraception)	value parameter	female_lit (% literate adult women)			
			awareness-ind (awareness of an individual of modern methods to control fertility)			
			WTFR (wanted total fertility rate)			
			Ci (representing use of traditional methods)			
policy controversy: family planning <-> modernisation				spearh_mass_com (effort devoted to mass communication)	steering variable	
				spearh_fam_plan (effort devoted to family planning programmes)	steering variable	
				spearh_education (effort devoted to education)	steering variable	
policy controversy: legalisation <-> prohibition			AR (number of induced abortions per live births)	abortion_leg (signifying whether abortion is legalized)	steering variable	
				spearh_abortion (effort devoted to provision of abortion facilities)	steering variable	

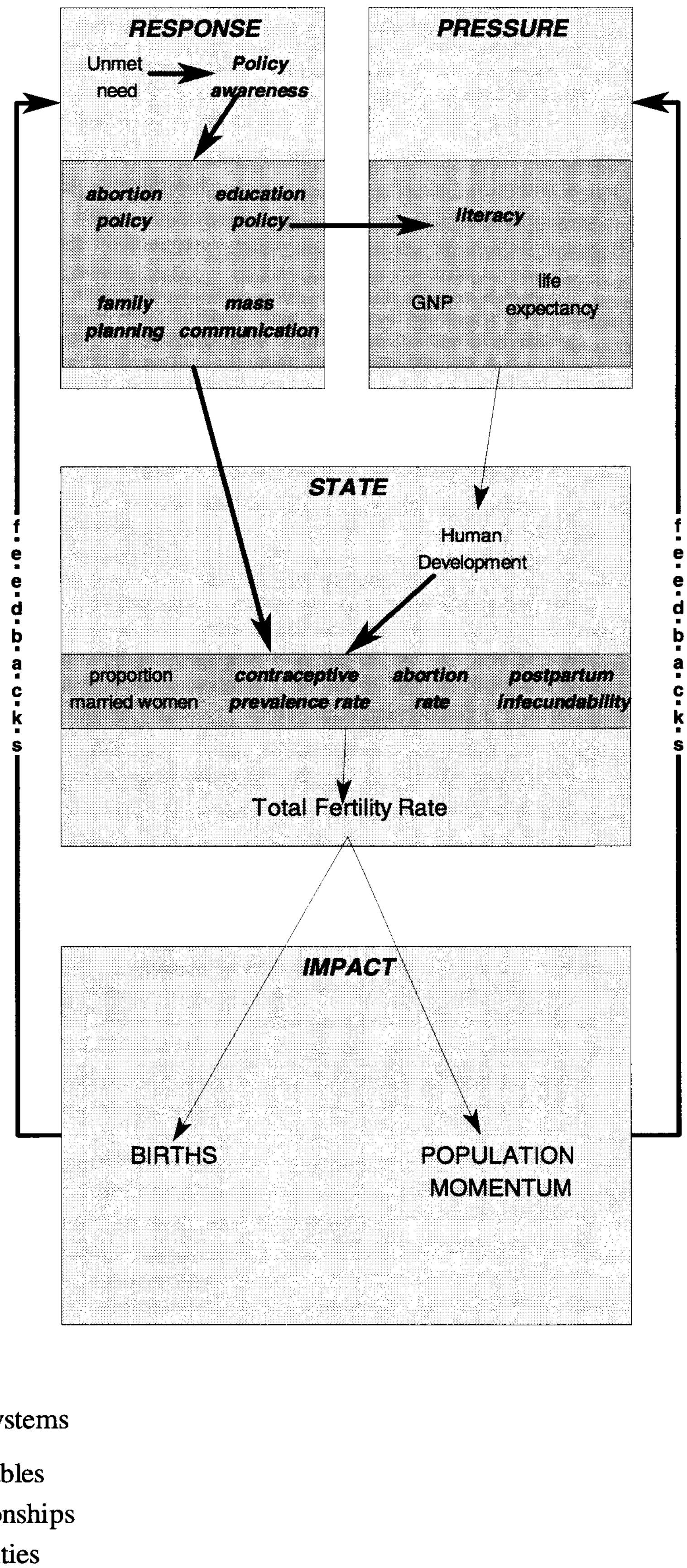


Figure 3.3: Loci of weak parts in the fertility submodel

Table 3.2 Importance of uncertainties

perspective-related uncertainty in model terms	magnitude	degree	time-variability	importance
policy_awareness	unknown, unknown	high	high	high
priority	unknown, unknown	high	high	high
diffusion_rate	large, known	low	middle	middle
female_lit	unknown, unknown	high	middle	high
awareness_ind	unknown, unknown	high	high	high
WTFR	unknown, unknown	high	high	high
Ci	large, unknown	middle	middle	high
spearh_mass_-comm	unknown, unknown	high	high	high
spearh_fam_plan	unknown, unknown	high	high	high
spearh_education	unknown, unknown	high	high	high
spearh_abortion	unknown, unknown	high	high	high
abortion_leg	unknown, unknown	high	high	high

degree and time-variability (see Chapter 2). The results of this ranking procedure are presented in *Table 3.2*. In the light of this ranking we may conclude that, with the exception of the *diffusion_rate*, all quantities and relationships are highly important. In other words the model relationships determining *policy_awareness, (policy) priority, female_lit, awareness_ind, WTFR, Ci* and *AR,* and the model quantities representing policy spearheads *spearh_mass_comm, spearh_fam_plan, spearh_education, abortion_leg* and *spearh_abortion* are the accessories for the alternative model routes. *Diffusion_rate* is used as a calibration factor.

3.4. Perspective-based alternative model routes

3.4.1. Introduction

The controversies concerning population growth are described from the viewpoints of each of the three active cultural perspectives, which yield differing coherent and consistent interpretations of model relationships and quantities. As explained in the previous Chapter, we assume, following Thompson *et al.* (1990), that all standpoints vis-à-vis the population issue lie on in the cultural continuum defined by the active cultural perspectives. Therefore, we should be able to locate the poles of the controversies as described in Section 3.1 on that continuum. As has been argued in the previous Chapter, two dimensions are distinguished: 1) world view and 2) management style. The hierarchistic, egalitarian and individualistic views are traced along both dimensions. The interpretations which adherents to the cultural perspectives bring to bear on the scientific controversies are indicated in *Figure 3.4.* The translations of the perspective's interpretations into modelling terms are discussed below.

3.4.2. The hierarchist

World view

The overall hierarchistic myth of nature (Nature Perverse/Tolerant) serves as the starting point. Applying this idea to the population issue leads to the conclusion that, due to the inherently finite capacity of the planet Earth (in particular its finite capacity to feed human beings), the present disequilibrium between fertility and mortality rates needs to be resolved. To this end, fertility levels would inevitably have to fall, especially in the developing countries where they are extremely high. From the hierar-

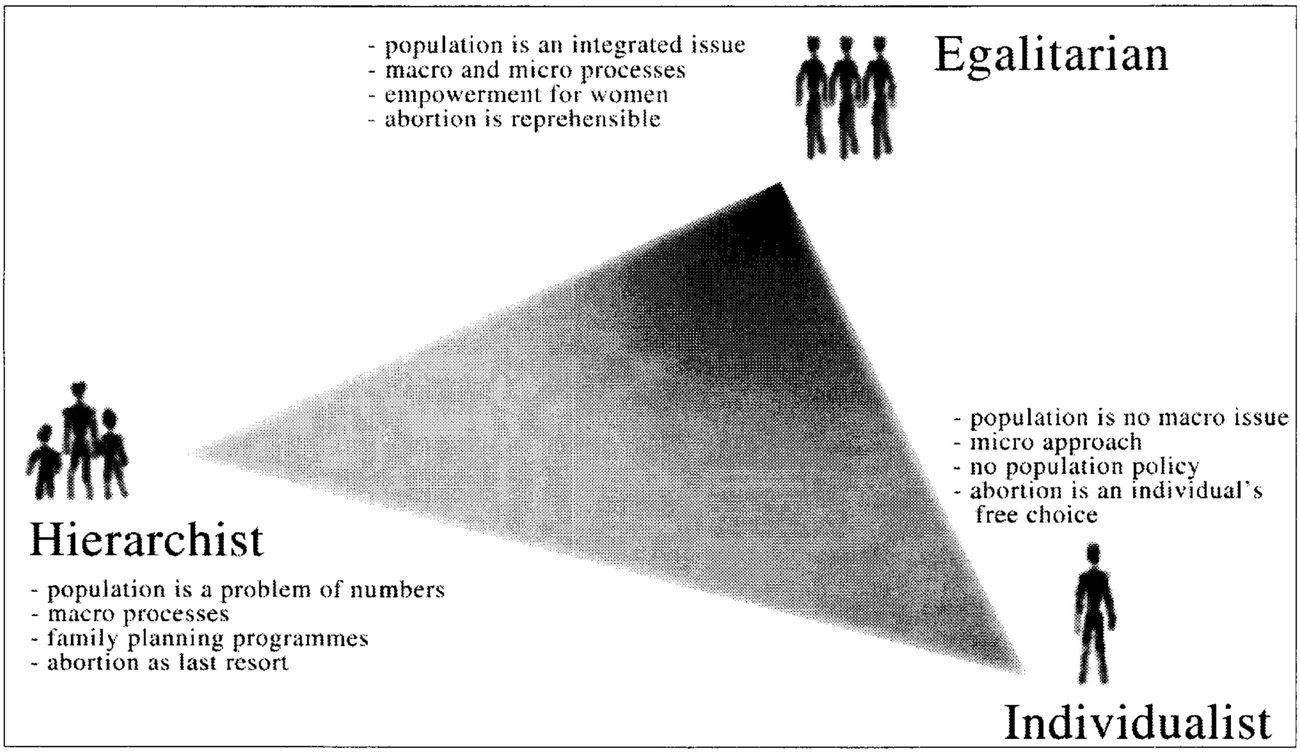


Figure 3.4: Perspectives on population growth and fertility change

chistic perspective changes in fertility behaviour only occur due to (top-down) macro incentives, which leads to the conclusion that family planning programmes, as the most prescriptive measure, primarily determine attitudes towards the use of contraceptives. A higher level of human development and mass communication efforts do not more than merely support such programmes. In model terms, this means that *awareness_ind* is primarily determined by the family planning efforts (in modelling terms: *PES*) and is only to a minor extent influenced by *HDI* and *mass_comm*. The desired family size prevalent at the level of individual couples (in modelling terms: *WTFR*) is also affected by the macro attitude towards population growth. *WTFR* is therefore determined by both the the level of human development (in modelling terms: *HDI*), and the effect of family planning (in modelling terms: *PES*).

As will be discussed below, from the hierarchistic perspective abortion is regarded as an essential means by which to control fertility as a last resort. Therefore, the number of abortions (in the model: *AR*) depends on the use and effectiveness of other methods of fertility control, represented by the contraceptive prevalence rate (in the model: *CPR*). The use of traditional methods of fertility control (represented by *Ci)*, such as prolonged breastfeeding and abstinence, will very probably vanish in the event of more reliable means of birth control being prevalent. The value of *Ci* is therefore determined as a function of the level of socio-economic development (in modelling terms: *HDI*).

The level of women's education, represented by *female_lit,* primarily depends on structural efforts to establish or improve the education system. In the fertility model, such efforts are assumed to correlate with human development (in modelling terms: *HDI).* Additional educational policy as part of population policy is considered to be of less importance. Therefore, *HDI* is the primary determinant of *female_lit*, whereas *education_pol* is seen as marginally affecting *female_lit*.

Manangement style

Faced with the actual explosive population growth, hierarchists perceive population policy as a question of controlling the numbers. In modelling terms, this means that *policy_awareness* as an indicator for the necessity of population policy is determined by the actual level of population in relation to an ultimate limit, which for modelling purposes is assumed to be 20 billion persons. The hierarchistic view has it that a dominant actor on a regional or global level is in a position to initiate policies in order to control population growth. Population measures are taken, because such an actor perceives a problem. In model terms, this means that *priority* is exclusively determined by the macro-feedback, i.e. *policy_awareness*. The emphasis is placed on family planning programmes, whereby education, mass communication and the provision of abortion facilities are seen as flanking and supporting measures. This leads to the following quantitative distribution of efforts: *spearh_fam_plan* = famplan_H = 0.9, *spearh_mass_comm* = (1-famplan_H)/3, *spearh_education* = (1-famplan_H)/3 and *spearh_abortion* = (1-famplan_H)/3. Because the emphasis in the hierarchistic management style is placed on control, no possible means should be excluded. Abortion is considered as means of last resort in fertility control, which implies that in the hierarchistic management style abortion is fully legalized, i.e. *abortion_leg* = 1.

3.4.3. The egalitarian

World view

If the egalitarians' myth of Nature (Nature Ephemeral) is applied to the population issue, explosive population growth is seen as being associated with catastrophic impacts on human society and the environment. Thus the egalitarian point of view can be described as based on the conviction that 'population growth is a socioeconomic and environmental problem'.

According to the egalitarian, changes in people's fertility behaviour result from both macro-processes and micro-processes: people change fertility behaviour according to individual aspirations and opportunities to control family size and in the light of the aspiration to contribute to an endurable future, both in the human and the environmental sense, a process which can be stimulated by incentives from governments. Insight into the condition of the human and the environmental system thus influences individual attitudes. In modelling terms, this means that *awareness_ind* is affected by population policies oriented towards communication and provision of contraceptives, namely: family planning programmes (in model terms: *mass_comm* and *PES*), individual desires to change fertility behaviour (in the model represented by *unmet_need*) and by modernisation (represented in the model by *HDI*). From the egalitarian point of view family planning programmes are only effective (that is capable of influencing the behaviour of couples) in a context of increasing human development, and, therefore, *HDI* and *unmet_need* are regarded as the primary determinants of *awareness_ind*. The desired familiy size is the result of individual choices, which are assumed to change as couples become more educated, a factor which is modelled by calculating *WTFR* as dependent on *HDI*. Due to the emphasis placed on the relation between education and fertility control, literacy (in modelling terms: *female_lit*) is assumed to be strongly influenced by additional educational efforts carried out within the scope of population policies (in modelling terms: *education_pol*).

The egalitarian abhors abortion for two reasons: 1) future children deserve life as much as we do and 2) it is a harmful and therefore unacceptable interference in womens' bodies. Couples will therefore generally abandon the use of abortion and take preventive measures to secure that no unwanted children are born, which implies that the number of induced abortions (in modelling terms: *AR*) equals zero. Where no modern contraceptives are available to satisfy the couples' need, they rely on traditional methods such as abstinence, which in the model is represented by *Ci*. This implies that *Ci* is determined by the *unmet_need*.

Management style

The egalitarian management style is characterized as preventive, i.e. egalitarians anticipate future developments and try to preclude undesired outcomes. In view of their perception of the population issue, the model's indicator *policy_awareness* is determined by reference to socio-economic prospects (measured by finding the discrepancy between GWP (Gross World Product) and population growth) and to the environmental outlook (in model terms: *X_envir*)[2]. The actual need for governmental population policy (in model terms: *priority*) is determined both by the evaluation of human and environmental prospects (in model terms: *policy_awareness*) and the individuals' inability to control their fertility (in model terms: *unmet_need*).

Egalitarians focus on stimulation of the empowerment of women in general and improvement of education in particular. The emphasis in the mix of policy instruments is, therefore, placed on education and mass-communication, whereby supplementary family planning programmes are sometimes used to provide access to means of contraception, although these programmes are not in themselves intended to stimulate a change in fertility behaviour. In view of the egalitarians' abhorrence of abortion in general, their management style envisages prohibition of

[2] In the fully-integrated version of TARGETS this indicator is to be derived from the model's environmental system. In the stand-alone version it is introduced as a dummy indicator.

abortion, so that, in the model, *abortion_leg* = 0. These preferences result in the following quantitative distribution of initiatives: *spearh_education* = educ_E = 0.8, *spearh_mass_comm* = 0.9 * (1-educ_E), *spearh_fam_plan* = 0.1 * (1 - educ_E) and *spearh_abortion* = 0.

3.4.4. The individualist

World view

For the individualist, Nature is a skill-controlled cornucopia (Nature Benign) and consistent with this perception, population growth is not seen as a macro-problem at all. If, on the level of individuals, smaller family sizes are preferred for self-seeking reasons, people seek and find the means to practice contraception. In model terms, this implies that *awareness_ind* equals *unmet_need*, signifying the individual's wish to control fertility. The desired family size (in model terms: *WTFR*) is a purely personal choice, which depends on the couple's self-seeking motives. The attitudinal change towards a smaller preferred family size is represented by a correlation with the level of development (in model terms: *HDI*). In this model route, *WTFR* exclusively depends on HDI.

In the event of unwanted pregnancies, couples are perfectly free to use abortion as a means of birth control. In view of the individualist's perception of people as self-seeking individuals, the number of abortions (in model terms: *AR*) depends on the number of unwanted pregnacies (represented by *unmet_need*). In cases in which individual couples can afford modern contraceptives, the use of traditional methods (in model terms: *Ci*) will vanish. *Ci* is, therefore, modelled as depending on *HDI*, signifying the general development which also indicates the couples' freedom of action.

Female_lit depends on the quality of the educational system, which is assumed to be represented by *HDI*.

Management style

The individualistic perception of the population issue implies that no explicit population policy is seen as being required. In view of this fact, in the individualistic alternative model route decision variables in the Response system are ignored (in modelling terms: all spearheads equal zero), except for the *abortion_leg* representing legalisation or prohibition of abortion. Individuals should be given all opportunity to control their fertility if they want to, and therefore abortion is fully legalised (in modelling terms: *abortion_leg* = 1).

3.5. Uncertainty Analysis

The alternative model routes, which are themselves combinations of world views and management styles, are used to construct 'utopias' and 'dystopias', enabling assessment of the consequences of consistent clustered interpretations of perspective-related uncertainties in the fertility model. First we compare the three utopias, followed by an analysis of the various dystopias in relation to those utopias. It should be noted that we used a preliminary model version, which has not yet been fully calibrated.

3.5.1. Utopias: scenarios

For each perspective, the associated world view is combined with the relevant preferred management style, and the fertility transitions, which are the results of this exercise, are presented in *Figure 3.5.* The 'historical' trajectories of each perspective, i.e. the model simulations for the period 1900 to 1990, are compared with historical data (UN, 1993; Bos *et al.*, 1992). The three utopias generated approximate the historical path reasonably well. Comparing the utopias with historical data suggests that the perspective-related uncertainties concerning fertility provide enough room for fundamentally differing explanations of the historical transition: history can be interpreted along each of the cultural perspectives. These results seem to be in line with the thesis advanced by Thompson *et al.* (1990) that due to (irreducible) uncertainties all perspectives provide equally viable, plausible, coherent and consistent theories to account for the observed changes. We need to subject the utopias to a sensitivity analysis to evaluate whether some of the parameters, which do not substantially differ in the alternative model routes, dominate the model outcomes. This would explain the similarities in the historical trajectories. Such a sensitivity analysis of the fertility model will be carried out during the second quarter of 1995.

What is the added value of our approach? Using the alternative and consistent interpretations and coherent clusters of the uncertainties, we **explain** why the generated scenarios are plausible and, even more important, that they are equally probable and possible. Using our approach based on cultural perspective-oriented uncertainty analysis it is possible to **understand** what uncertainty means for our assess-

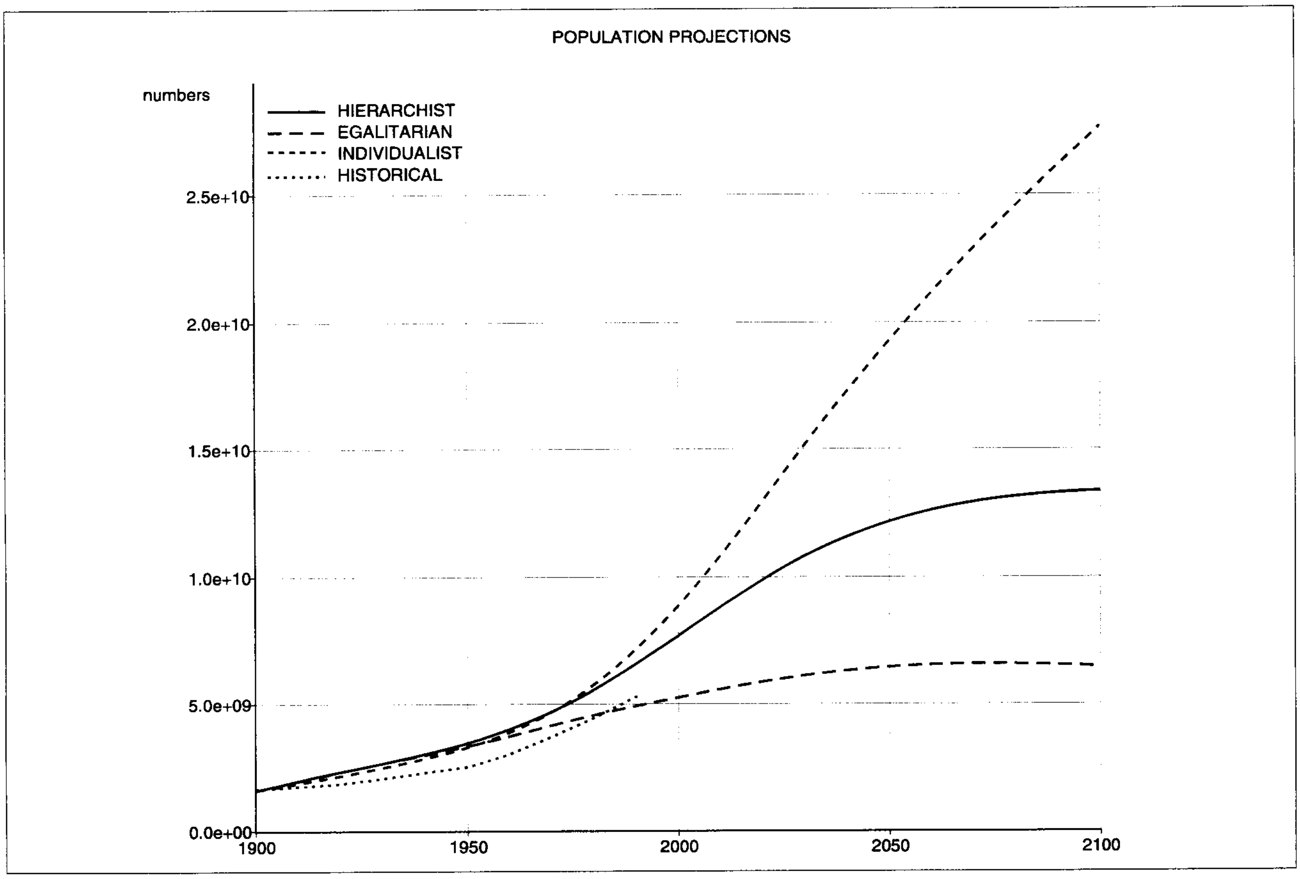


Figure 3.5: Utopian projections and historical data

ments of the future. In this way, scenario choices can be systematically motivated, instead of being based on the 'rules of thumb' in the pragmatic approach which has hitherto been adopted. Consistent scenarios which can be criticised in terms of clear and coherent motivations of the underlying choices help decision-makers to understand the consequences of uncertainties for decision-making.

3.5.2. Dystopias: risks in decision-making under uncertainty

For each perspective the preferred management style is now juxtaposed with the alternative two world views. What need do such experiments fulfill? Juxtaposition of the response strategy of a perspective with a dystopian world view teaches us what might happen in the event of reality failing to correspond to a perspective's world view. Dystopias can be used to assess the risks of such a strategy in the face of uncertainty.

Dystopias plus egalitarism

Analysis of the juxtaposition of dystopian world views with the egalitarian management style (i.e. where the main focus is on education policy and prohibition of abortion) shows that the egalitarian strategy might cause serious problems (*Figure 3.6*): I) juxtaposed with the individualistic world view, the egalitarian strategy, although intensified relative to the efforts in the utopian situation, results in an explosive population growth with a population number of 25 billion in 2050, which is about fourfold the egalitarian utopian situation and II) juxtaposed with the hierarchistic world, the effect of the egalitarian strategy again results in more effort than in both the utopian and the individualistic dystopian situation, and leads to an even more catastrophical exponential population growth, passing the level of 30 billion people already before 2025. In view of the egalitarian perspective, in which population growth is perceived as a problem, we may conclude that due to the uncertainties the risk accompanying the egalitarian strategy is high. Not only are population numbers higher in both dystopias, but human development also lags behind the utopian projection of the future. In particular, adherents to the egalitarian perspective suffer from the fact that the perspective-based analysis is performed with only the population system of

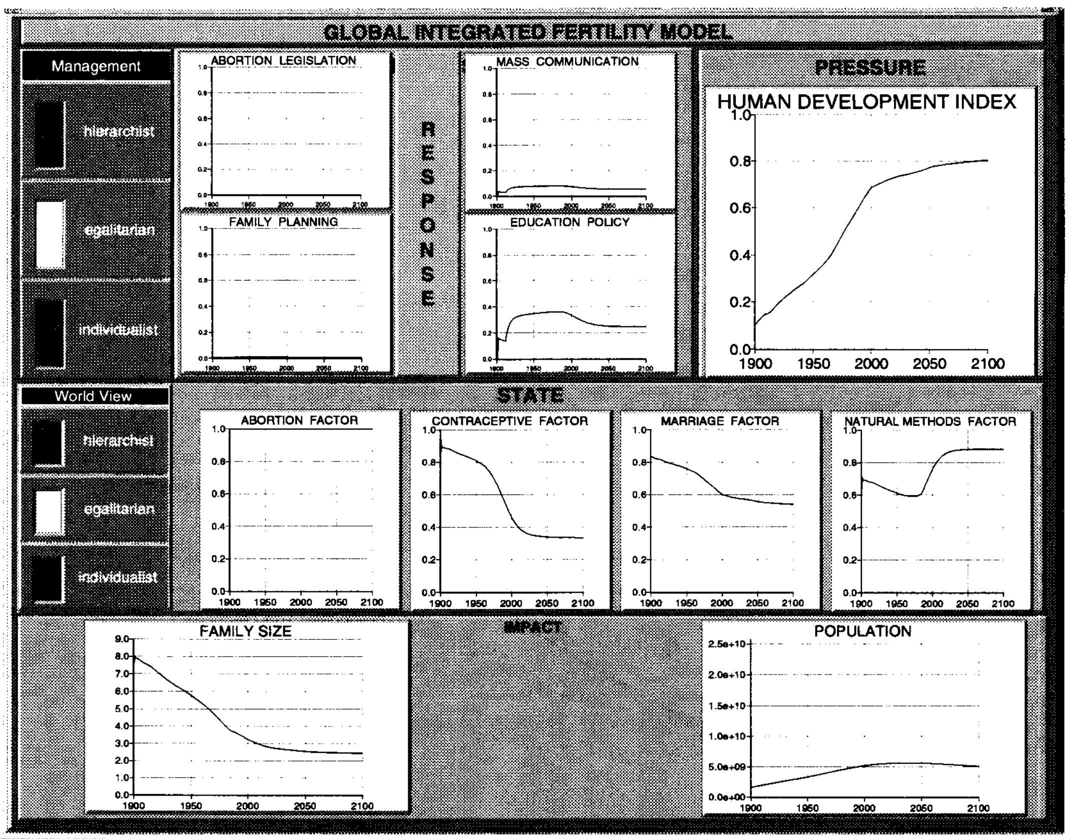
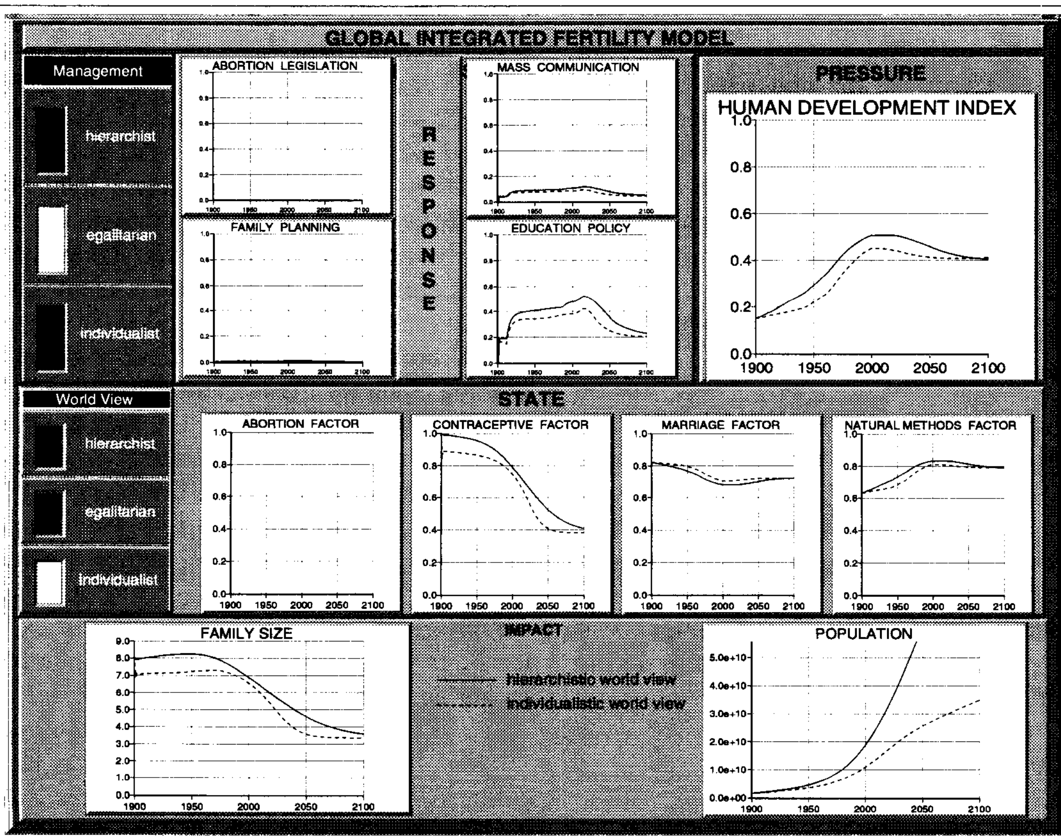


Fig 3.6a: Egalitarian utopia

Fig 3.6b: Egalitarian dystopias



TARGETS. A more comprehensive reflection of the egalitarian perspective would need to take account of a fully-integrated version of the entire TARGETS model.

Dystopias plus hierarchism

Evaluation of the juxtaposition of the hierarchistic management style (i.e. main focus on family planning and legalisation of abortion) with the dystopian world views yields a dissimilar estimation of risk (*Figure 3.7*): I) juxtaposed with the individualistic world view, the hierarchistic strategy with an effort comparable to the utopian situation, results in increasing population number (up to about 26 billion people in 2100) with a decline in the rate of growth and II) juxtaposed with the egalitarian world view, the result is a fast exponential population growth, which passes the level of 25 billion before 2050. The moderate family planning effort in the egalitarian dystopia is misleading: due to the estimated ultimate carrying capacity (of 20 billion people) family planning stabilizes in the generated dystopian scenario after 2020, because family planning is of no worth if that biological limit would be passed. Regarding the hierarchistic emphasis on population numbers and its estimation of an ultimate limit of about 20 billion people, its management style is relatively risky in both dystopian cases.

Dystopias plus individualism

Where risks related to decision-making under uncertainty are concerned, analysis of the dystopias vis-à-vis the individualistic management style is of less importance. Neither the level of population nor population growth is considered to constitute a problem, and because fertility behaviour is regulated by micro-level processes, population policy (on a macro level) has no priority at all. Although the dystopias generate futures which differ significantly from the individualist's utopia (see *Figure 3.8*), the differences cannot be expressed in terms of risk, because population characteristics are of no consequences as evaluation criteria in the eyes of the individualist.

Experiments employing utopias and dystopias can be used to render explicit, to analyse and to improve the strategy adopted by adherents to one of the perspectives. For example, if the egalitarian wants to avoid the risk of a future world inhabited by more than 50 billion people (the hierarchistic utopia), the hierarchistic policy options might be used to construct a strategy which no longer aspires to a situation as ideal as in the utopia, but which nevertheless reduces the risk of a catastrophic development. Thus, uncertainties are no longer hidden, but are rather used in a **constructive** manner as building blocks in fashioning a new methodology in scenario development. Such an assessment assists decision-makers in selecting the most 'promising' strategies. 'Promising' is here defined as meaning 'as close to the perspective's utopian situation as possible with as little risk as possible'.

3.6. Conclusion

Perspective-based alternative model routes enable us to analyse the consequences of demographic uncertainties arising from subjective judgment and disagreement among experts in a systematic, consistent and quantitative manner. In this way, we can attribute the overall uncertainty associated with fertility projections to (relatively) specific sources of uncertainty. Such insights might be used to (re)write the research agenda being followed by demographic scientists. Alternative routes through the model can also serve to facilitate communication within and outside the demographic community, since they enable scientists to analyse competing theories and explanations of fertility transition in a transparent and quantitative manner.

This brief case study of the application of our methods to the fertility model has, we hope, gone some way towards demonstrating that the methodology of perspective-based alternative model routes might be a fruitful one. The cultural perspectives provide consistent and coherent model routes which can be used to analyse competing demographic projections. The model experiments expose motives underpinning projections such as those of the United Nations agencies (UN, 1993) and World Bank (Bos *et al.*, 1992). The alternative model routes enable demographic scientists to readjust projections systematically and in an insightful manner when new scientific evidence and new empirical facts have been established.

Alternative model routes 'translate' demographic uncertainties into risks associated with specific policy strategies. Regarding the fact that the concept of uncertainty apparently is rather incomprehensible and unmanageable for decision-makers, we hope to provide an approach which could facilitate communication between scientists and decision-makers. The discussion of the fertility case study indicates

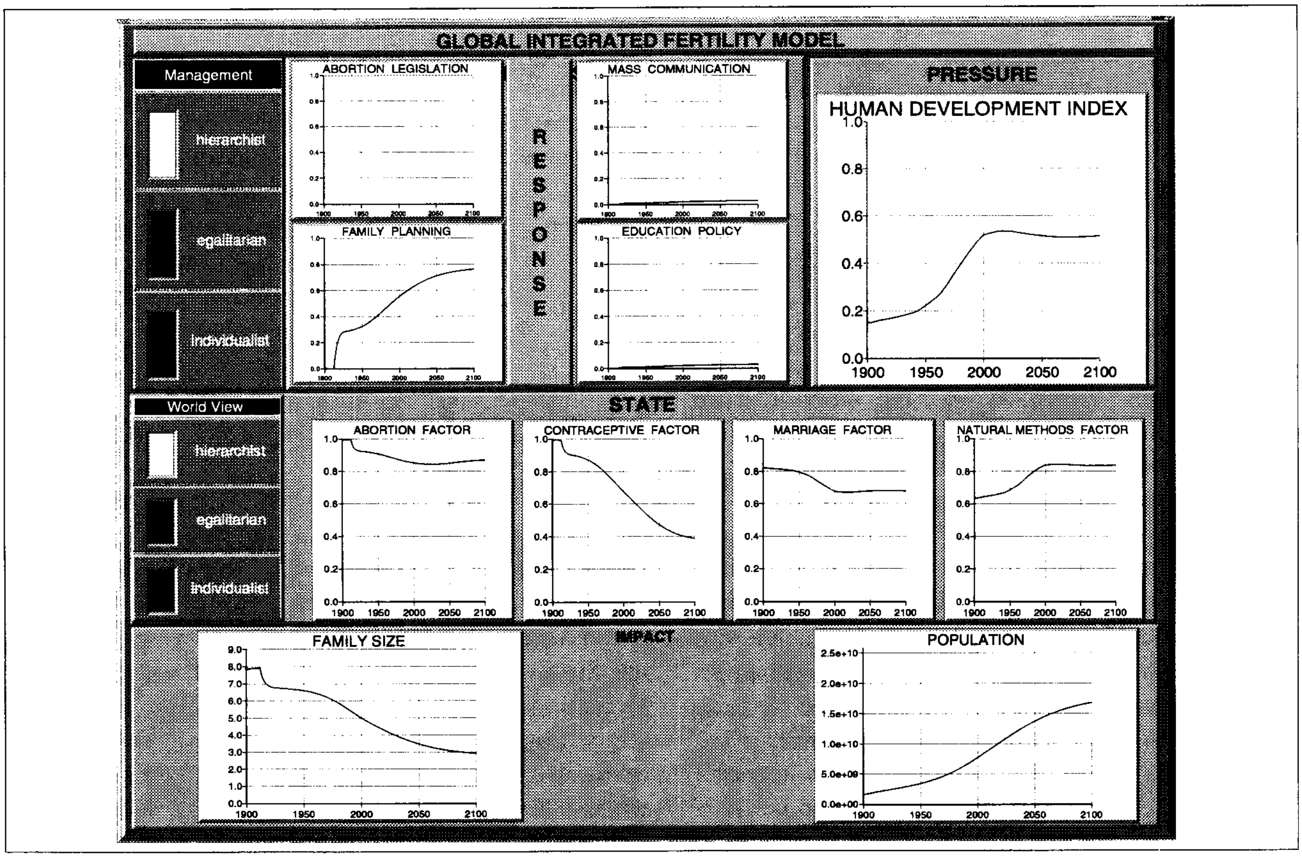
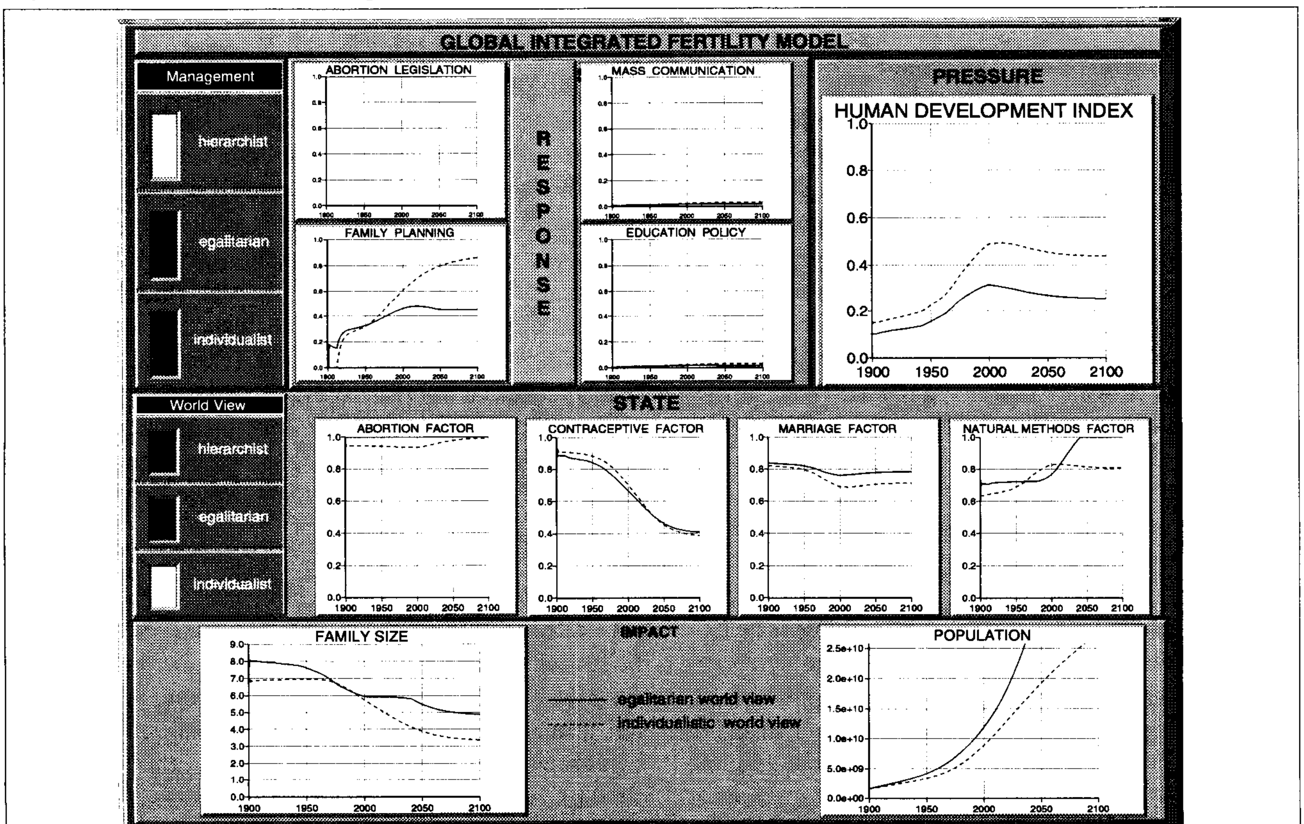


Figure 3.7a: Hierarchistic utopia

Figure 3.7b: Hierarchistic dystopias



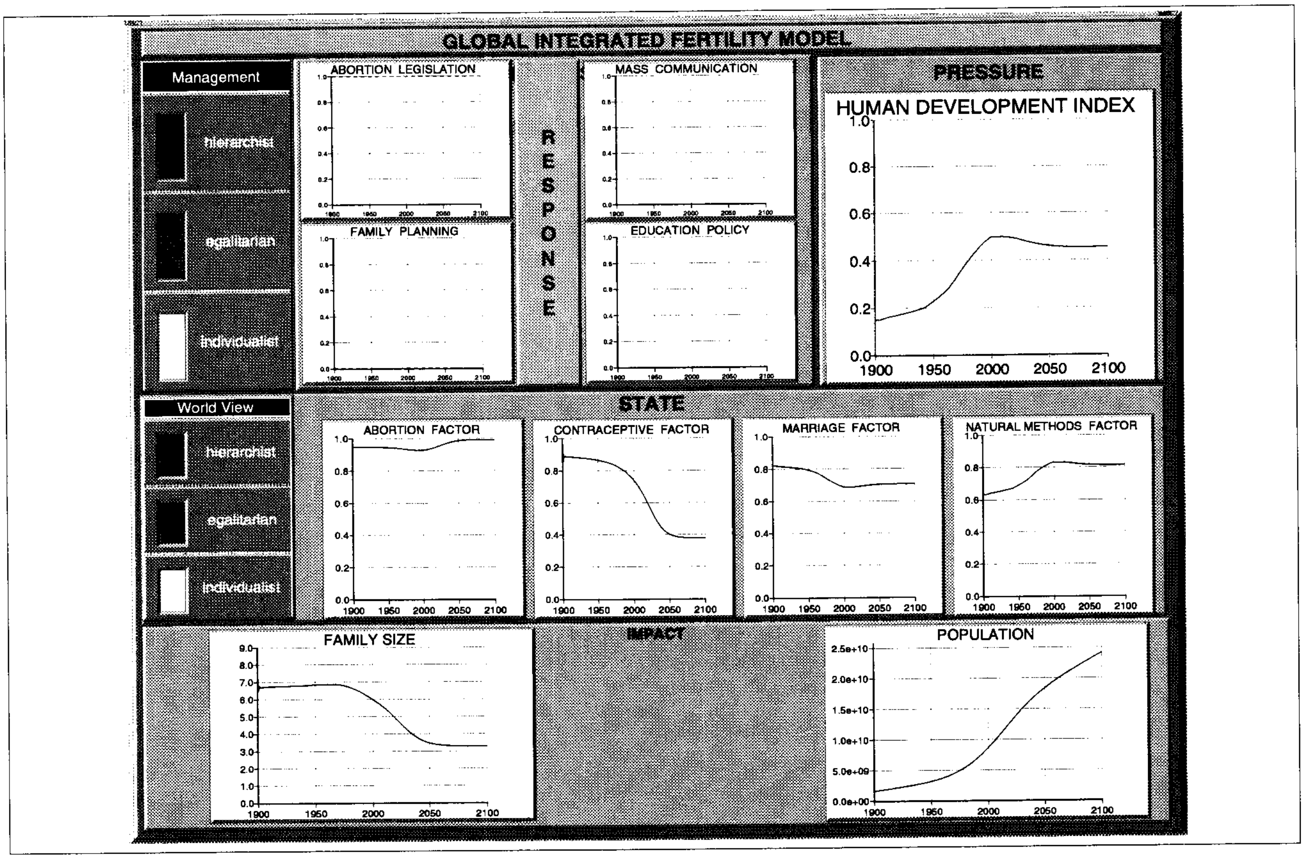
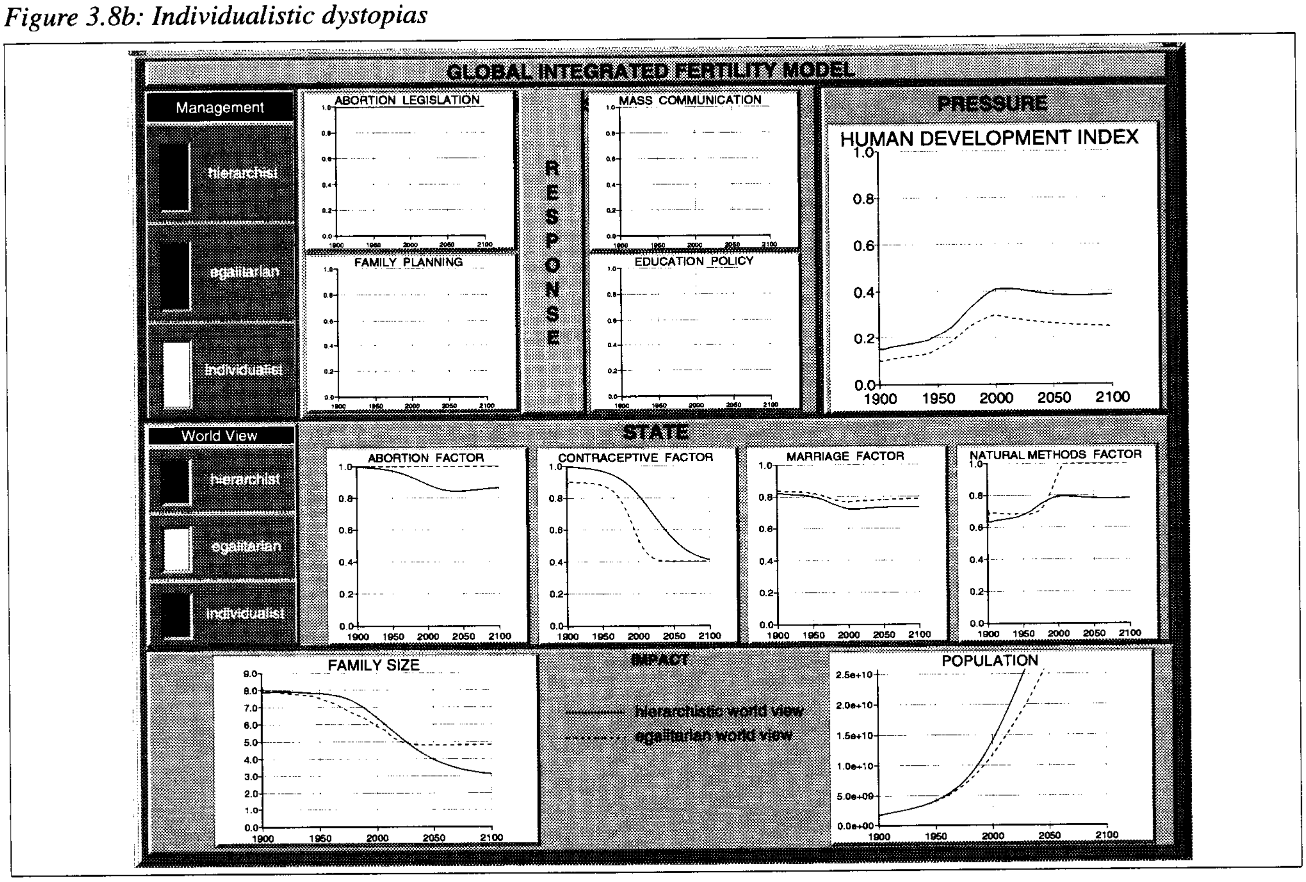


Figure 3.8a: Individualistic utopia

Figure 3.8b: Individualistic dystopias



that the assessment of uncertainties can be used constructively as an element in the methodology of scenario development. Instead of treating uncertainties as the most problematic issue in modelling, for which reason they are usually hidden, we hope to uncover the constructive potential of the identification, illumination and analysis of uncertainties as means of facilitating communication among scientists as well as between scientists and decision-makers, and thereby advocate a new methodology for scenario development. We expect that integrated assessment models augmented with alternative model routes which modulate uncertainty can improve the process of decision-making under conditions of uncertainty.

4. ALTERNATIVE MODEL ROUTES: *CASE STUDY BASED ON THE CLIMATE ISSUE*

4.1. Introduction

Uncertainty is a ubiquitous factor in global climate research. Global climate scientists struggle to understand the complex relationships among the numerous physical, biological and chemical processes that comprise the dynamics of the global environment. No one can say with much certainty how, or even whether, the doubling of the CO_2 levels in the atmosphere will change the Earth's environment and what the socio-economic impacts will be if it occurs. The magnitude and complexity of uncertainty surrounding the question of global climate change has made it difficult to answer even the most simple and important question: whether we should act now or wait until more is known about the global environment. Therefore, uncertainty must be dealt with explicitly and rigorously in global integrated assessment models designed to assess climate change. Analytical methods for uncertainty representation, uncertainty elucidation and the estimation of risks are necessary. Here, we use perspective-based alternative model routes for identification, illumination and clarification of uncertainty in the biogeochemical cycles submodel (hereafter also referred to as the CYCLES-submodel (Den Elzen *et al.*, 1995)), a module of the global integrated assessment model TARGETS. Although we intend to analyse the whole CYCLES submodel, the present study is limited to the climate part of the model. It was not possible to implement the alternative routes into the CYCLES submodel, due to delays in the model development. The present Chapter should, therefore, be conceived as a feasibility study.

It should be stressed that the primary goal of the case study based on the CYCLES submodel is to demonstrate the applicability of the methodology of (cultural) perspective-based alternative model routes to integrated assessment models originating from the natural sciences. The case study does not aim at an exhaustive overview of the uncertainties surrounding climate change, and neither does it take account of the most recent insights, it is simply intended to demonstrate the main uncertainties and controversies which can be rendered visible and tangible in integrated assessment models. The present Chapter should not be regarded as arguing for or against any particular standpoint in the scientific climate debate, but rather as an attempt to clarify the concept of scientific uncertainties in the minds of decision-makers by describing how the key uncertainties can be rendered explicit in integrated assessment models.

4.2. The state-of-the art

Research on climate change is based on a range of scientific disciplines: atmospheric chemistry, biology, ecology, hydrology, glaciology, and climatology. The present study primarily focuses on the enhanced greenhouse effect, i.e. the additional warming caused by human activities. The Earth's surface air temperature is significantly modified by a natural greenhouse effect. Without this natural process the mean surface air temperature of the Earth would be some 33 °C lower. Since the beginning of the industrial era, the emissions of most greenhouse gases have increased substantially. The direct result of this change in the atmospheric energy balance is an additional warming of the troposphere. Various feedbacks within the climate system, however, may either stimulate or impede this warming process and, while the net effect is certainly positive, the exact magnitude of the warming process is as yet a subject of much debate. Observations of global-mean temperature at the Earth's surface over the last 130 years have shown a warming of the troposphere between 0.3° and 0.6 °C (Folland *et al.*, 1992). Attributing this warming unequivocally to an increase in the atmospheric concentration of greenhouse gases, however, remains problematic owing to the variability of climate due to other factors such as aerosols (Wigley, 1989; Charlson *et al.*, 1991; Charlson *et al.*, 1992; Taylor and Penner, 1994; Wigley, 1994), variations in solar radiation (Kelly and Wigley, 1990), and volcanic eruptions (Hansen *et al.*, 1992). If such a climate change occurs, it will certainly prove irreversible for the next hundred years: the effects of global warming would continue to make themselves felt for at least a century.

The state-of-the-art uncertainties concerning processes and feedbacks are described along the following topics: emissions of greenhouse gases, biogeochemical cycles, atmospheric chemistry and climatology. Complicating factor in such an overview is to estimate the compound effect of simulta-

Table 4.1: Components of the carbon dioxide mass balance (based on Watson et al., 1990)

Component	*1980-1989 (GtC/yr)*	
CO_2 emissions	7.0 ± 1.1	observed
Uptake by the oceans	2.0 ± 1.0	model-based
Change in atmospheric mass of CO_2	3.4 ± 0.2	observed
Uptake by terrestrial biota	1.6 ± 1.4	calculated based on mass-balance

neous processes and feedbacks (see IPCC, 1994).

4.2.1. Emissions of Greenhouse Gases

Gases which are recognized as greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxides (NO_x), chlorofluorcarbons (CFCs) and halochlorofluorocarbons (HCFCs). Currently accepted theory has it that carbon dioxide currently constitutes about 55% of the gases responsible for enhanced greenhouse forcing while its concentration is rising at a rate of about 0.5% a year (IPCC, 1990; 1992). The main sources of carbon dioxide are the combustion of fossil fuels and land use changes (primarily deforestation). Because carbon dioxide is considered to be the most important greenhouse gas, the present study focuses on uncertainties related to the increase in CO_2 concentrations, although effects of SO_x (mainly in the occurrence of sulphate aerosols) on radiative forcing are taken into account. SO_x is not, strictly speaking, a greenhouse gas, but affects global warming indirectly, as will explained later on. Scientists are uncertain about the magnitude of the sources of the various greenhouse gases. Insofar as the total CO_2 emissions are concerned, the contribution from fossil fuel combustion is relatively well-documented (with an estimated error of about 5% (Marland, 1991)), but the emissions associated with land use changes have not yet been properly quantified (potential error in the order of 50% (IPCC, 1990)).

4.2.2. Bio-geochemical cycles

Research on global bio-geochemical cycles encompasses the role of physical, chemical and biological processes in and between the atmosphere, the oceans and the terrestrial biosphere within the carbon (C), sulphate (S), phosphorus (P) and nitrogen (N) cycles. In this Chapter we concentrate on the climate-related aspects of the biogeochemical cycles of C, N and S, associated with the greenhouse gases: CO_2, CH_4 and NO_x, and sulphate aerosols. We propose to focus our attention on the carbon cycle.

The natural carbon cycle involves the annual exchange of hundreds of billions of carbon molecules in the form of CO_2 between three reservoirs: the atmosphere, the oceans and the terrestrial biosphere. Because CO_2 is a non-biodegradable element, the total uptake is inevitably 100%. Anthropogenic CO_2 emissions are disturbing this natural balance (Rotmans and Den Elzen, 1993). For the period 1980-1989 the emissions and uptake of the reservoirs of CO_2 are summarized in *Table 4.1*. Scientists are uncertain about the magnitude of the sinks of CO_2. With respect to the oceanic and terrestrial carbon sinks, the likely errors are of the order of approximately 100%. The only well-documented component of the global carbon cycle is the amount of carbon remaining in the atmosphere, although recent measurements of CO_2 in the atmosphere show a levelling off of the concentration, while the emission rate has not stabilized at all. The scientific community cannot explain this trend: even if the emissions have been stabilized, stabilization of atmospheric CO_2 could not have occurred as soon, since time lags are involved (Sarmiento, 1993).
Although much of the uncertainty regarding the uptake by oceanic and terrestrial biosphere sinks arises from lack of adequate data, inadequate understanding of the key processes and of the many potential biogeochemical feedbacks also play a role. Pivotal processes inherent to the carbon cycle could be disturbed directly by the fluctuations in atmospheric CO_2 concentrations, or indirectly by human-induced global warming associated with biogeochemical feedbacks. Uncertainties within this field are directly attributable to lack of knowledge about biogeochemical feedback mechanisms. The feedbacks may affect the concentration of greenhouse gases themselves and may alter the response of the

climate system and thereby indirectly either amplify (positive feedback) or dampen (negative feedback) the initial response of the climate system. For the purposes of the present study we propose to draw a distinction between terrestrial (terrestrial-biosphere-atmosphere) and oceanic (ocean-atmosphere) processes and feedbacks.

Terrestrial processes and feedbacks

Processes in the biosphere can be classified into the categories of: uptake of CO_2 by vegetation (vegetation uptake), vegetation respiration and vegetation albedo. Enhanced atmospheric CO_2 concentrations and increased temperature affect the above processes by means of biogeochemical feedback mechanisms. Many of the feedbacks have been documented, but most of them have been only hinted at by researchers. In this section, the relatively known feedback processes are briefly discussed.

<u>Vegetation uptake</u>
Regarding vegetation uptake four feedbacks are distinguished: 1) carbon dioxide fertilization effect, 2) soil moisture retention changes, 3) nitrogen fertilization and 4) migration of ecosystems.

1) carbon dioxide fertilization effect
Higher atmospheric CO_2 concentrations can stimulate the accumulation of carbon in vegetation. This process, referred to as the CO_2-fertilization effect, is a negative feedback mechanism which inhibits the temperature response signal.

2) soil moisture retention changes
Carbon storage in terrestrial biota is affected by changes in soil water which may occur as a result of a rise in temperature.

3) nitrogen fertilization
The primary production of many ecosystems is determined by the availability of nutrients, primarily nitrogen. Increases in the concentrations of NO_x and NH_x emissions resulting from industrial and anthropogenic activities is associated with an increase in primary productivity and thereby constitutes a negative feedback with regard to climate change (IPCC, 1990, 1992).

4) migration of ecosystems
Climate change could cause a geographical migration of biota. It is possible that, for example, forests will not be able to find new habitats as quickly as their climate belt shifts, and the resulting dying and decaying trees will release additional CO_2 into the atmosphere.

<u>Vegetation respiration</u>
The temperature effect on respiration results in an increased release of CO_2 concentrations into the atmosphere (positive feedback).

<u>Vegetation albedo</u>
Climate change (as well as the geographical distribution of terrestrial ecosystems due to human activities) will also affect the surface albedo. A poleward shift in the tundra-boreal forest boundary could result in a decreasing albedo. Increases in grassland and desert caused by human activities could result in an increase in the surface albedo. Current knowledge, however, is insufficient to quantify this effect.

Oceanic processes and feedbacks

Insofar possible, the climate-related oceanic processes and feedbacks are even less known than the terrestrial processes discussed above. If one regards the ocean as a sink for CO_2, four relevant processes can be distinguished: ocean diffusion, ocean circulation, ocean biology and ocean chemistry. These extremely complicated and only partially understood processes are only caricaturally discussed below.

<u>Ocean diffusion</u>
Warming the upper ocean layer may delay diffusion of CO_2 into the ocean water. This decreases carbon transport to the deeper ocean, thereby slowing oceanic uptake of atmospheric CO_2. Moreover, it retards heat uptake by the deep ocean, thus amplifying climate warming effects.

<u>Ocean circulation/ convection</u>
Global warming could diminish cooling of water masses in the polar regions and thus influence horizontal and vertical ocean circulation. The associated decrease in upwelling rates in tropical and temperate oceans results in less upwelling of CO_2-rich deep water. Due to non-linearities and freakishness of these natural processes, the uncertainties could prove to be highly significant.

<u>Ocean biology</u>
Estimations of CO_2 absorption are based on hypotheses about the behavior of plankton, although little is known about them. Moreover, the disturbance of ocean circulation due to global climate change may prove to have a negative impact on biological productivity.

Ocean chemistry

Ocean chemistry can be influenced by warming of the sea water, causing a decrease in CO_2-solubility and thus a lower net uptake of atmospheric CO_2 by the oceans.

4.2.3. Atmospheric chemistry

The most important uncertainties in this field concern tropospheric chemistry, i.e. tropospheric "lifetimes" and the rate of reaction of the various chemical elements. Furthermore, due to temperarure changes in the atmosphere associated with climate change the atmospheric dynamics can change. A crucial factor is the oxidyzing capacity of the troposphere, i.e. the concentration of OH-radicals.

4.2.4. Radiation

The term 'forcing' is used to refer to the effect of exogenous factors on the changes in the atmospheric energy balance (Charlson and Wigley, 1994). In the event of an instantaneous doubling of anthropogenic CO_2 emissions, the radiative forcing of the surface-atmosphere system would be about 4.3 Wm^{-2}. The change in the global mean surface temperature is related to this radiative forcing. In absence of any feedbacks, a doubling of anthropogenic CO_2 emissions would lead to a global mean surface temperature increase of 1.2 °C. Uncertainties in this field of knowledge are (in order of importance) due to: 1) the radiative effect of aerosols (Charlson and Wigley, 1994); 2) the radiative effect of ozone depletion on the rate of forcing; and, to a far less extent to 3) the radiative effects of greenhouse gases. The first two will be discussed briefly below.

Aerosols

The role of aerosols in dispersing solar radiation has recently been recognized in climate change theory. Sulphates are the best understood aerosols. Other aerosol substances -soot derived from fossil fuel combustion, dust storms and emissions resulting from slash-and-burn agriculture- may have an impact approaching the magnitude of that caused by sulphates. Lack of sufficient and reliable data exacerbates the uncertainties associated with such effects. Sulphate aerosols, in contrast to greenhouse gases, are responsible for "global cooling". They do this in two ways, namely by: 'direct' and 'indirect' effects on the radiative forcing. The direct effects involve incoming solar radiation simply being reflected, and thus never reaching the Earth's surface and contributing to tropospheric warming. The aerosols affect the reflection of solar radiation indirectly by clouds. Clouds form in the atmosphere when relative humidity reaches 100%, but water vapour cannot readily condense in the absence of a nucleation site. Aerosols provide these sites, known as condensation nuclei, thereby determining the number of droplets formed in the cloud. If all other things are equal, (the range of cloud altitude and liquid H_2O content of the cloud), clouds which are composed of a larger number of condensed drops reflect more solar radiation than clouds holding fewer drops of condensation. If the aerosol concentration is increased by anthropogenic aerosols, clouds will form which carry a larger number of condensation drops and thus reflect more radiation.

Ozone depletion (stratospheric ozone)

The problems of climate change and ozone depletion are interrelated, not only by virtue of their common sources, but also as a consequence of the numerous interactions between the two phenomena (Den Elzen, 1993). These direct and indirect interactions occur according to atmospheric chemistry. Negative radiative forcing due to ozone depletion, a direct interaction, was demonstrated by Ramaswamy *et al.* (1991) and the WMO (1992). Depletions of ozone in the lower stratosphere during the last decade have caused reductions in radiative forcing occurring in the surface-troposphere system which could, on a global scale, balance out enhanced direct radiative forcing.

Most interactions are indirect. The increase in UV-B radiation reaching the oceans due to stratospheric ozone depletion might negatively affect plankton production, which would reduce the CO_2-uptake in the oceans, thus amplify initial global warming. Moreover, stratospheric ozone depletion influences the formation of tropospheric ozone, which is a greenhouse gas and as such of importance in contributing to the enhanced greenhouse effect.

4.2.5. Climatology

The task of climatology is to describe the climate system driven by processes in the hydrosphere (including cryosphere), terrestrial biosphere and atmosphere. Uncertainties are due to insufficient knowledge on the characteristics of geophysical feedbacks under present and future circumstances.

Geophysical feedbacks

Geophysical feedbacks are associated with physical processes in the atmosphere-ocean-terrestrial biosphere system and directly affect the initial response of the climate system. The most important geophysical feedbacks are 1) the water vapour feedback, 2) the snow-ice albedo effect and 3) the cloud feedback.

Water vapour feedback

This feedback mechanism is probably best understood and most important. Global warming increases the amount of water vapour, which being a greenhouse effect agent, amplifies the initial warming (positive feedback). In the event of a doubling of atmospheric CO_2, this feedback would amplify surface warming and increase it by between 1.2 °C and 1.9 °C.

Snow-ice albedo feedback

This feedback mechanism contributes to the enhancement of global warming in two ways. Firstly, a warmer Earth has less snow and ice cover and the planet becomes less reflective and absorbs more solar radiation. Secondly, changes in thermal inertia due to melting ice and snow affect the thermal capacity of the ocean-ice-atmosphere system. Both processes amplify initial warming, albeit that the latter process is of more importance.

Cloud feedback

The feedback mechanisms related to clouds are the most complex. Clouds contribute to warming in the climate system by reducing infrared radiation high in the atmosphere, but they also produce a cooling effect through absorption and reflection of solar radiation. The net effect, which depends on the height, the structure and the surface area of clouds, is in the present situation negative. How the outcomes will change under climatic disruptions is still uncertain due to the complexity of this feedback mechanism.

Due to climate change, the global cloud volume could decrease. Thus, the Earth would be able to emit infrared radiation more efficiently, a negative feedback mechanism. Besides, less solar radiation would be reflected by clouds, which in turn amplifies global warming (positive feedback). Global warming could initiate redistribution of clouds: if clouds are displaced to higher and colder altitudes, they will emit less radiation and thus amplify the initial warming.

These complex mechanisms clearly illustrate the uncertainties associated with the cloud feedback. The dominant estimation, however, is that the compound effects of clouds constitutes a positive feedback.

Moreover, the snow-ice albedo feedback and cloud feedback interact with each other, which makes it precarious to even estimate their separate contributions to the enhanced greenhouse effect. The effect of geophysical feedbacks is usually expressed in terms of climate sensitivity, i.e. the equilibrium global surface temperature increase due to a doubling of carbon dioxide levels.

Heat uptake

An important source of uncertainty in the field of climatology is the incomplete understanding of the absorption of thermal energy by oceans. As stated above, however, biogeochemical feedbacks in the oceans could disturb diffusion and circulation, which are important determinants of the heat capacity of oceans.

An overview of the current uncertainties and their (potential) effects on global climate change can be found in *Table 4.2*.

4.3. Characterization of the uncertainties

Modelling global climate change implies dealing with the uncertainties in the light of state-of-the-art scientific knowledge. We propose to use the overview of uncertainties, given in the previous section, as a starting point in our examination of uncertainties in the biophysical submodel of TARGETS. In this Section we will elaborate on the uncertainties in more detail, in order to provide a ranking of importance, which will serve as point of departure to determine which of the uncertainties must be identified, illuminated and clarified by reference to alternative model routes. As set out in Chapter 2, three indicators to determine the importance are used, namely, in order of priority: magnitude (*Table 4.3*), degree (*Table 4.5*) and time-variability (*Table 4.4*).

In the particular case of climate change, when we consider the degree of uncertainty we must bear in mind that in some cases it is not known whether the process or feedback has a dampening or amplifying effect (i.e. negative or positive effect respectively, as set out in *Table 4.2*) on climate change. In cases in which the potential magnitude is qualitatively estimated but the sign of the effect is not known, we deem the degree of uncertainty to be high.

Table 4.2 Effect of uncertainties on climate change

process	uncertainty	effect on climate change
chemical cycli		
ocean:		
* primary processes	ocean dynamics	+
* secundary processes	temperature feedbacks on biology, chemistry, circulation and diffusion	+/?
	behaviour of plankton	?
biosphere		
* primary processes	CO_2-fertilization	-
	N-fertilization	-
	soil moisture changes	?
* secundary processes	migration of ecosystems	?
	temperature feedback on respiration	+
	temperature feedback on net primary production	-
	temperature feedback on albedo	+
atmospheric chemistry		
* primary processes	lifetimes of greenhouse gases	?
	rates of reactions	?
* secundary processes	feedback on lifetimes	?
radiation		
* primary processes	aerosols: direct effect	-
* secundary processes	aerosols: indirect effect	-
	stratospheric ozone	-
	solar flux radiation	
climatology		
atmosphere- ocean - biosphere		
* geophysical feedbacks	water vapour	+
	snow-ice-albedo	+
	clouds	?
ocean-atmosphere		
	ice-ocean feedback	-

+ means amplify, ? means effect is unknown, - means dampens initial global warming

Table 4.3 Magnitude of uncertainties

process	uncertainty	magnitude qualitatively	magnitude quantitatively	references
chemical cycli				
ocean				
* primary processes	ocean dynamics	middle	unknown	IPCC, 1992, 1994
* secundary processes	temperature feedbacks on biology, chemistry, circulation and diffusion	small	unknown	Klepper et al., 1994 IPCC, 1992, 1994
	behaviour of plankton	small	unknown	Klepper et al., 1994
biosphere				
* primary processes	CO_2-fertilization	large	unknown (uncertainty > 50 %)	IPCC, 1994 Emanuel, 1985 Rotmans et al., 1993 Den Elzen, 1993
	N-fertilization	middle	unknown	Peterson and Melillo, 1985 Schlesinger, 1993 Schindler and Bayley, 1993 IPCC, 1992, 1994
	soil moisture changes	large	unknown	Mellillo et al, 1993 Schimel et al., 1990 Shaver et al., 1992 IPCC, 1994
* secundary processes	migration of ecosystems	middle	unknown (uncertainty > 50%)	Solomon and Leemans, 1990 Leemans, 1990 Smith and Shugart, 1993 IPCC, 1990
	temperature feedback on respiration	large	unknown (uncertainty > 50%)	Melillo et al., 1993 Rotmans et al., 1993 IPCC, 1992, 1994 Den Elzen, 1993
	temperature feedback on net primary production	large	unknown (uncertainty > 50%)	Melillo et al., 1993 Rotmans et al., 1993 IPCC, 1992, 1994
	temperature feedback	middle	unknown (uncertainty > 50%)	IPCC, 1990, 1992, 1994
atmospheric chemistry				
* primary processes	lifetimes of greenhouse gases	middle	known (uncertainty < 30%)	Prather et al., 1992 Den Elzen, 1993
	rates of reactions	middle	known (uncertainty ± 10%)	Prather et al., 1992 Den Elzen, 1993
* secundary processes	feedback on lifetimes	small	unknown	Rotmans et al., 1992 Prinn, 1994

continued on next page

Table 4.3 continuation

process	uncertainty	magnitude qualitatively	magnitude quantitatively	references
radiation				
* primary processes	aerosols: direct effect	large	unknown (uncertainty > 50%)	Wigley, 1994 Charlson and Wigley, 1994 Taylor and Penner, 1994 Charlson et al., 1991 Keith and Morgan, 1994
* secundary processes	aerosols: indirect effect	large	unknown	Charlson and Wigley, 1994 Wigley, 1994 Taylor and Penner, 1994 Charlson et al., 1991
	stratospheric ozone	small	unknown (uncertainty 100%)	Ramaswamy et al., 1992 Isaksen et al., 1992 Wigley, 1992 Den Elzen, 1993
	solar flux radiation	middle	unknown	IPCC, 1992, 1994
climatology				
atmosphere- ocean - biosphere				
* geophysical feedbacks	water vapour	large	unknown	Ramanathan, 1989 Gates et al., 1992
	snow-ice-albedo	middle	unknown	Dickinson, 1986 Ingram et al., 1989 Cowey et al., 1991 Gates et al., 1992 Den Elzen et al., 1993
	clouds	large	unknown	Ramanathan and Collins, 1992 Gates et al., 1992 Den Elzen, 1993
ocean-atmosphere	ice-ocean feedback	middle	unknown	Hibler, 1984 Kemke et al., 1990 Gates et al., 1992

Studying climate change, time-variability can be illustrated by examining estimations of climate sensitivity during the past decades. *Figure 4.1* charts the climate sensitivity as calculated using various expert models between 1975 and 1992, and as estimated by present climate experts (Morgan and Keith, 1994), as well as the range of climate sensitivity as estimated by the Climate Research Board (1979), Dickinson (1986), IPCC (1990), IPCC (1992) (all in: Den Elzen, 1994) and by climate experts (Morgan and Keith, 1994). These results tell us that over the last few decades the central estimate of climate sensitivity has fallen from 3.5 °C in the mid-eighties to 2.5 °C (-30%) (IPCC, 1990; 1992; Morgan and Keith, 1994) at present, which indicate a high time-variability.

To offer an example of how it is possible that uncertainty can increase as time passes by: for years the amount of carbon remaining in the atmosphere was considered well-known. Recent measurements, however, lead to the so-called 'missing carbon sink', indicating that the uncertainty has increased rather than decreased.

Morgan and Keith (1994), for example, assess the time-variability associated with uncertainty, by asking experts to indicate the amount of uncertainty reduction they believed could be achieved if research could completely remove uncertainty associated with each of the following items: cloud optical properties, convection/water vapour feedback, CO_2

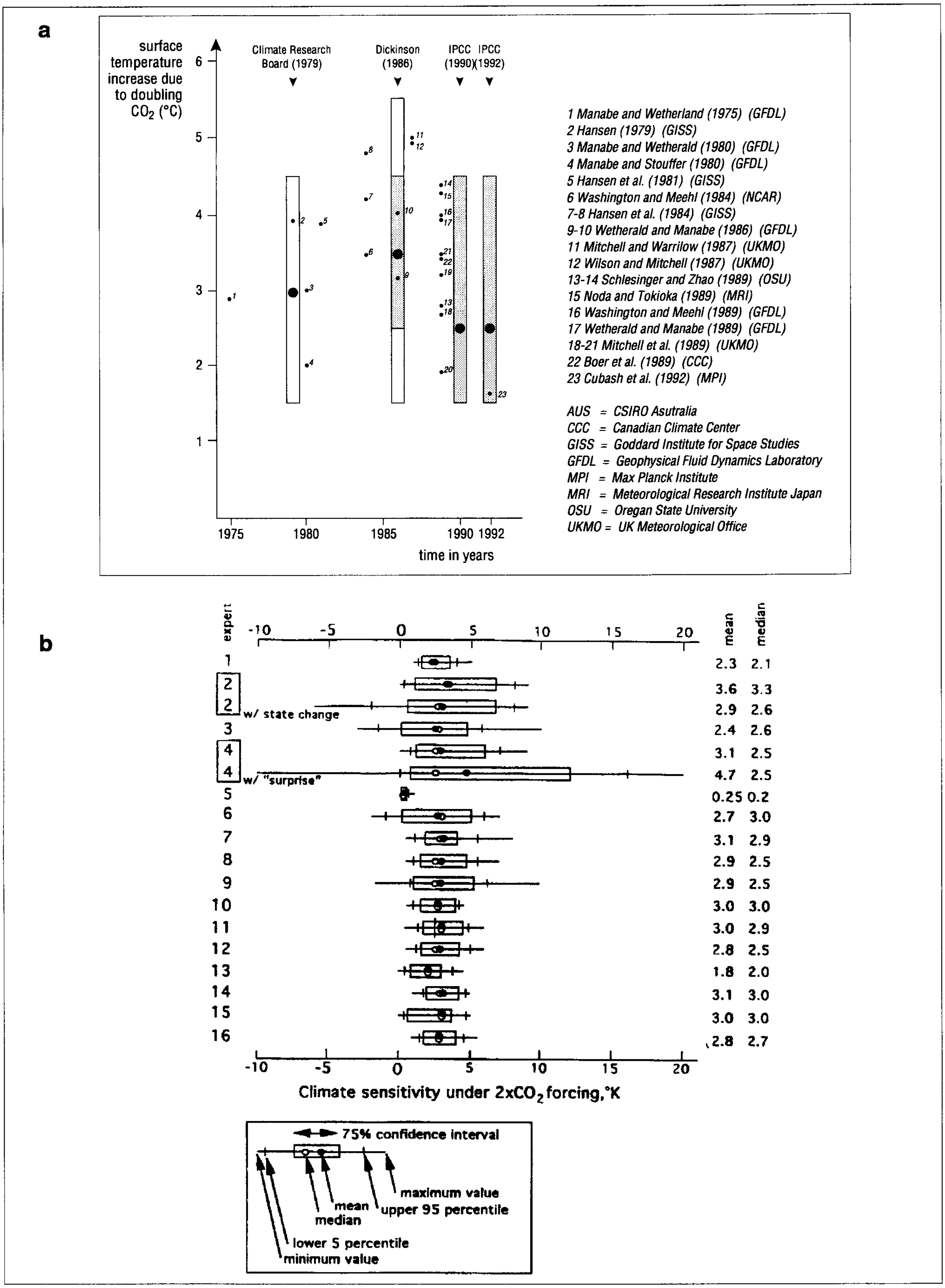
Table 4.4: Time-variability of uncertainties

process	uncertainty	time variability (low, middle, high)
chemical cycli		
ocean		
* primary processes	ocean dynamics	low
* secundary processes	temperature feedbacks on biology, chemistry, circulation and diffusion	middle
	behaviour of plankton	low
biosphere		
* primary processes	CO_2-fertilization	high
	N-fertilization	middle
	soil moisture changes	middle
* secundary processes	migration of ecosystems	middle
	temperature feedback on respiration	middle
	temperature feedback on net primary production	middle
	temperature feedback on albedo	middle
atmospheric chemistry		
* primary processes	lifetimes of greenhouse gases	high
	rates of reactions	high
* secundary processes	temperature feedback on lifetimes	high
radiation		
* primary processes	aerosols: direct effect	middle
* secundary processes	aerosols: indirect effect	high
	stratospheric ozone	middle
	solar flux radiation	middle
climatology		
atmosphere- ocean - biosphere		
* geophysical feedbacks	water vapour	middle
	snow-ice-albedo	middle
	clouds	high
ocean- atmosphere		
	ice-ocean feedback	middle

Table 4.5: Importance of uncertainties

process	uncertainty	magnitude (large, middle, small; known, unknown)	degree (high, middle, low)	time-variability (high, middle, low)	importance (high, middle, low)
chemical cycli *ocean*					
* primary processes	ocean dynamics	middle, unknown	middle	low	middle
* secundary processes	temperature feedbacks on biology, chemistry, circulation and diffusion	small, unknown	high*	low	low
	behaviour of plankton	small, unknown	high*	low	low
biosphere					
* primary processes	CO_2-fertilization	large, unknown	middle	high	high
	N-fertilization	middle, unknown	middle	middle	middle
	soil moisture changes	large, unknown	high*	middle	high
* secundary processes	migration of ecosystems	middle, unknown	high*	middle	high
	temperature feedback on respiration	large, unknown	middle	middle	high
	temperature feedback on net primary production	large, unknown	middle	middle	high
	temperature feedback on albedo	middle, unknown	middle	middle	middle
atmospheric chemistry					
* primary processes	lifetimes of greenhouse gases	middle,known	low	high	middle
	rates of reactions	middle, known	low	high	middle
* secundary processes	temperature feedback on lifetimes	small, unknown	middle	high	low
radiation					
* primary processes	aerosols: direct effect	large, unknown	middle	middle	high
* secundary processe	aerosols: indirect effect	large, unknown	middle	middle	high
	stratospheric ozone	small, unknown	middle	middle	low
	solar flux radiation	middle, unknown	middle	middle	middle
climatology ***atmosphere- ocean - biosphere***					
* geophysical feedbacks	water vapour	large, unknown	middle	middle	high
	snow-ice-albedo	middle, unknown	middle	middle	middle
	clouds	large, unknown	high*	high	high
ocean-atmosphere	ice-ocean feedback	middle, unknown	middle	middle	middle

* means that the degree is influenced by uncertainty of the effect on climate change (see *Table 4.1*)



expert	mean	median
1	2.3	2.1
2	3.6	3.3
2 w/ state change	2.9	2.6
3	2.4	2.6
4	3.1	2.5
4 w/ "surprise"	4.7	2.5
5	0.25	0.2
6	2.7	3.0
7	3.1	2.9
8	2.9	2.5
9	2.9	2.5
10	3.0	3.0
11	3.0	2.9
12	2.8	2.5
13	1.8	2.0
14	3.1	3.0
15	3.0	3.0
16	2.8	2.7

Figure 4.1: a) climate sensitivity as calculated between 1975-1992 (source: Den Elzen, 1993)
b) climate sensitivity as expressed by climate experts (source: Morgan and Keith, 1994)

Table 4.6 Crucial uncertainties (in arbitrary order)

* CO_2-fertilization
* soil moisture
* migration of ecosystems
* temperature feedback effect on vegetation respiration
* temperature feedback effect on net primary production
* direct effect of aerosols
* indirect effect of aerosols
* water vapour (geophysical feedback)
* clouds (geophysical feedback)

exchange with biota, CO_2 exchange with oceans, and oceanic convection (Morgan and Keith, 1994). Approximately half of the respondents stated that the uncertainty about the climate sensitivity would be reduced by more than 20% if all uncertainty were eliminated from convection/water vapour feedback or from cloud optical properties. Approximately half believed that their uncertainty about climate sensitivity would be reduced by more than 10% if all uncertainty were eliminated from CO_2 exchange with oceans, CO_2 exchange with biota or oceanic convection. Morgan and Keith (1994) also assess potential discoveries which could increase or decrease uncertainty associated with climate sensitivity.

The indicators magnitude, degree and time-variability are used to determine relative importance (*Table 4.5*). In view of this ranking we may conclude that the uncertainties summarized in *Table 4.6* (in arbitrary order) are to be considered as being the most important.
If we check our classification against the ranking which Morgan and Keith (1994) set out, thereby studying their interviews with 16 climate experts of different schools of thought. Morgan and Keith aimed at articulation of subjective expert judgments. Part of their effort was to rank the factors contributing to the experts' uncertainty. Three different ordering procedures (numbers of mentions, weighted number of mentions and weighted sum of number of mentions) all yield the same top five factors across the set of all experts. The results are summarized in *Table 4.7*.
Comparison of our selection with the ranking of Morgan and Keith teaches us that our selection fits well with the top of their list: clouds, indirect and direct effects of aerosols as we distinguish are subsumed by 'cloud optical properties' (1); water vapour as geophysical feedback is the uncertainty factor of secondary importance on the list compiled by Morgan and Keith (2); and CO_2-fertilization, temperature feedback effects on respiration and net primary production respectively, soil moisture changes and migration of ecosystems are to be considered as crucial components of what Morgan and Keith call 'CO_2 exchange with terrestrial biota' (3).

4.4. Perspective-based alternative model routes

The uncertainties concerning global climate change result in disagreement among experts and subjective judgment. The controversies connected with the vital uncertainties in the state-of-the-art knowledge as selected in the previous Section are described in terms of the active cultural perspectives. While the CYCLES submodel of TARGETS primarily focuses on the biogeochemical cause-effects-chains where emissions are inputs from other submodules, such as energy, economy and land, and the output is determined in terms of temperature and precipitation changes, no explicit decision variables are to be distinguished in the CYCLES submodel. We therefore focus on the world views associated with the cultural perspectives and are content to merely indicate what kind of management would fit with each perspective's preferences. The model routes are summarized in *Table 4.8*.

4.4.1. The hierarchist

World view

Hierarchists interpret uncertainties in the manner in which prominent scientific experts and institutions (such as the Intergovernmental Panel on Climate Change (IPCC)) do, i.e. the hierarchists take the central values as estimations or 'best guesses' of the uncertainties. With reference to the selected crucial uncertainties, we take the central estimates published by the IPCC (1990; 1992; 1994) as a starting point to describe the hierarchistic interpretation. Within the SOAR-exercise, which is part of the Human Dimensions of Global Environmental Change Programme (HDGECP), Thompson and others substantiate that the IPCC scenarios essentially reflect the hierarchistic world view and therefore lack the requisite variety needed to account for all cultural perspectives (Trisoglio *et al.*, 1994) (see *Figure 4.2*). In other words, we adopt the central IPCC estimations of the uncertainties as guidelines to describe the hierarchist's perspective, because the IPCC's view of the world reflects the hierarchistic perspec-

Table 4.7 Ranking of uncertainty factors (Morgan and Keith, 1994)

rank	uncertainty factor	weighted sum of weighted ranks
1	cloud optical properties (including aerosol effects) - D	9.20
2	convection/water vapour feedback - D	7.13
3	CO_2 exchange with terrestrial biota - B	3.90
4	CO_2 exchange with oceans - B	3.60
5	oceanic convection - D	2.46
6	spatial resolution of ocean models - M	2.40
7	effect of flux correction on results of coupled models - M	1.75
8	initial state of ocean - D	1.60
9	large-scale atmospheric dynamics - D	1.43
10	large-scale ocean dynamics - D	1.40
11	land surface interactions - D	1.35
12	ice-ocean feedback (salt-pump) - D	1.06
13	ice-albedo feedback - D	1.00
14	all ocean response and coupling - D	0.80
15	clear sky properties of aerosols - D	0.80
16	solar flux radiations - B	0.80
17	ocean/atmosphere bulk transfer laws - D	0.80
18	aerosol chemistry and physics - B	0.75
19	methane non-antropogenic sources and all sinks - B	0.46
20	atmospheric boundary layer physics - D	0.33
21	oceanic quasi-vertical mixing processes - D	0.15

B denotes terms involving forcing and boundary conditions
D denotes terms involving system dynamics
M denotes terms having to do with the mechanics of modelling

tive (Trisoglio *et al.*, 1994; Janssen and Rotmans, 1994) and because the hierarchists are likely to follow the recommendations of respected scientists who are gathered together in the IPCC.

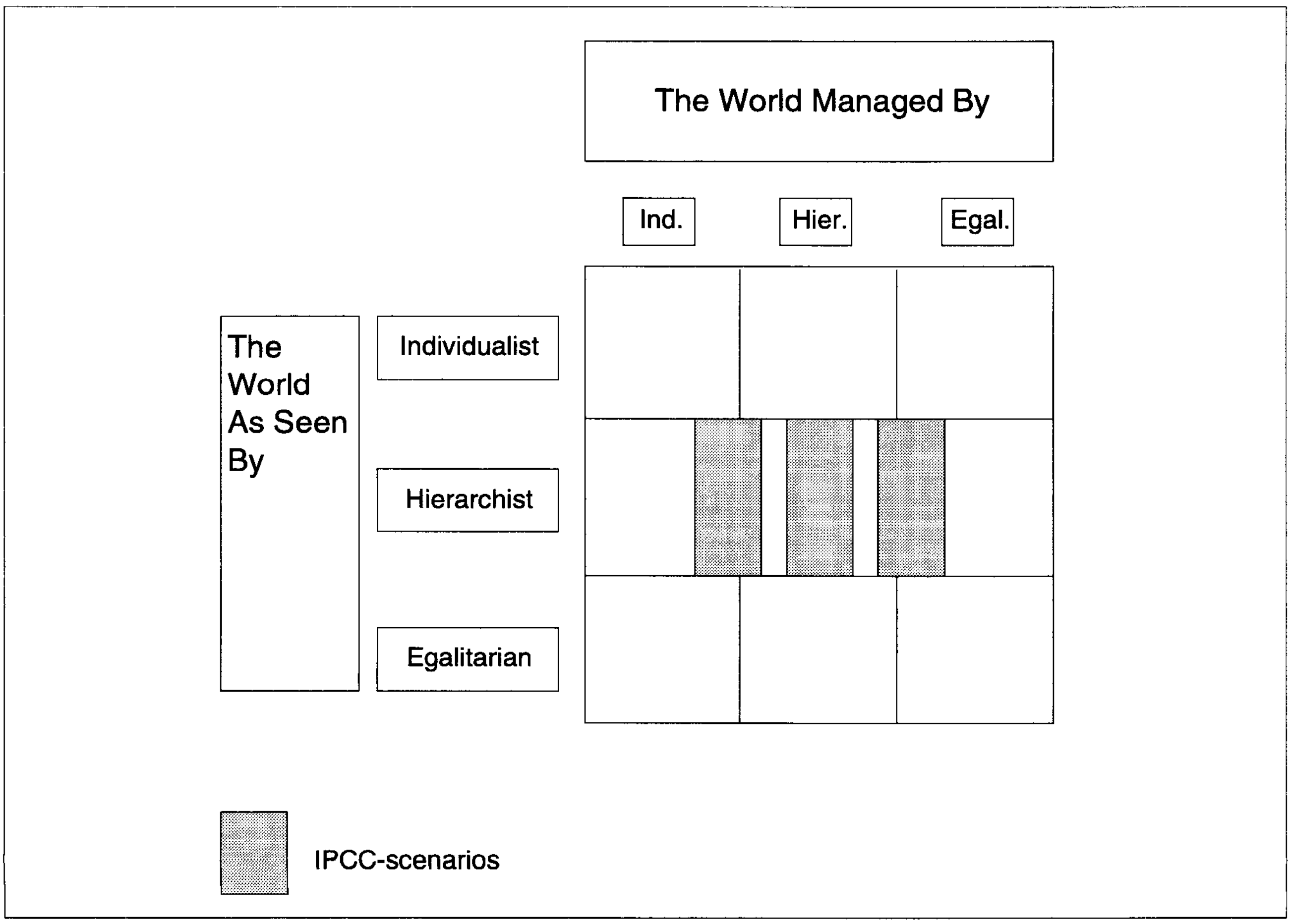
According to the hierarchistic myth of nature, i.e. Perverse/Tolerant, nature is stable within certain limits. The enhanced greenhouse effect is considered as a possible "knocking of the ball over the rim". For the hierarchists the main challenge is to figure out what disturbance of the climate system will cause serious and irreversible problems. Consistent with their inherent tendency towards control, they are inclined to leave speculations concerning possible processes and feedbacks aside. They will tend to take into account processes and feedbacks whose probability of occurrence and magnitude are known to a certain extent, i.e. processes with a degree of uncertainty garded as "middle" or "low" (*Table 4.3*). Applied to the selection of uncertainties, this means that processes such as soil moisture changes, migration of ecosystems and the geophysical feedback due to clouds are ignored in the hierarchistic description of the processes and feedbacks influencing climate change.

CO_2-fertilization is usually modelled by the fertilization factor (β), which reflects the fractional increase in the biological net primary production due to a fractional increase in atmospheric CO_2 concentration. The central estimate for this factor is 0.40 (Rotmans and Den Elzen, 1993), signifying that an increase in atmospheric CO_2 concentration has a moderately positive effect on the terrestrial uptake of CO_2.
The magnitude of the temperature feedback on net

Tabel 4.8: Alternative model routes

	hierarchist	**egalitarian**	**individualist**
CO_2-fertilization	$\beta = 0.4$	$\beta = 0$	$\beta = 0.7$
soil moisture changes	neglected	amplifying effect	dampening effect
migration of ecosystems	neglected	amplifying effect	dampening effect
temperature feedback on respiration	$Q_{10}^{res} = 2.0$	$Q_{10}^{res} = 4.0$	$Q_{10}^{res} = 0.8$
temperature feedback on primary production	parabolic function optimum range 20-35°C	parabolic function optimum range 18-25°C	continuously increasing function
direct effect of aerosols	$Q_{sox, direct} = 0.3$	neglected	$Q_{sox,direct} = 0.9$
indirect effect of aerosols	20% of direct effects	neglected	$Q_{sox,indirect} = 1.3$
water vapour (geophysical feedback)	$\lambda = 2.5$	$\lambda = 5.5$	$\lambda = 1.5$
clouds (geophysical feedback)	neglected	amplifying effect $\lambda = 5.5$	dampening effect $\lambda = 1.5$

Figure 4.2: IPCC scenarios lack variety



primary production is dependent on the temperature domain. Above 0 °C, photosynthesis initially responds rapidly to temperature increase, but slows down in an optimum range, and then decreases to zero at higher temperatures. This response is ecosystem-dependent. Within the hierarchistic perspective the optimum range is 20-35 °C (Rotmans and Den Elzen, 1993), signifying that net primary production will increase in the event that the temperature rises within this domain.

The effect of climate change on soils and humus respiration, which is expressed by a Q_{10} value (Q_{10}^{res}), indicating the rate of intensification of each process given a 10 °C temperature rise, for which 2.0 is used as central estimate (Rotmans and Den Elzen, 1993).

Regarding the direct and indirect effects of aerosols, the hierarchist adopts the central estimates, in which the sulphate aerosols are considered to substantially influence the radiative forcing, i.e. $Q_{sox,\ direct} = 0.3$. Where the indirect effects are more uncertain, the hierarchist considers those effects to be less substantial and assumes them to lie in the range of about 20% of the direct effects.

When it comes to interpretation of the uncertainties associated with the effects of geophysical feedbacks, the hierarchist exclusively takes the effect of the water vapour into account. Within the CYCLES model the geophysical feedbacks are represented by the climate sensitivity (λ), i.e. the temperature rise in the event of a doubling of atmospheric CO_2. The hierarchist estimates λ as being 2.5, the central estimate of the IPCC.

Management style

The challenge to the hierarchist lies in determining at what levels of anthropogenic pressures climate change will become a major threat, i.e. cause major structural changes, rather than merely innocuous disturbance of the system. The hierarchist therefore stresses the need for scientific research in order to determine those levels. In order to retain the ability to control the system in the future, for the time being the hierarchist advocates "no-regret" policies (or "least-regret" policies (NRP, 194)), and "end-of-pipe" technologies, but, on the other hand, shuns policies aiming at structural social, cultural and economic changes.

4.4.2. The egalitarian

World view

According to the egalitarian myth of nature (Nature Ephemeral), minor changes disproportionately influence the behaviour of the system. Consistent with their view of climate change as a catastrophic threat, they consider all uncertain processes and feedbacks as having amplifying effects on the human-induced disturbance of the global climate. Speculations about amplifying feedbacks or catastrophical impacts, which are strongly disputed within the scientific community, are also taken into account, whereas potential negative feedbacks are ignored.

When the egalitarian applies this principle to the selected uncertainties, CO_2-fertilization and the direct and indirect effects of aerosols are to be considered as chimeras. Although experiments in laboratories may show that an increase in CO_2 leads to an increasing photosynthetic rate in individual species, according to the egalitarian the complex ecosystems in the real world will not respond in such way because the laboratory conditions will not be relevant if there is a disturbance of the equilibrium conditions.

Even if aerosols had a dampening effect, directly and indirectly, on the imminent temperature increase, this would be an undesired effect because aerosols mostly result in acidification, which is another crucial threat to terrestrial ecosystems. Therefore, pinning one's hope to aerosols, it is not a sustainable solution to the problem of climate change because these substances involve the continuance of other environmentally detrimental effects.

The temperature feedbacks affecting net primary production will only be positive in the sense that productivity increases within a very small optimum range, i.e. slight temperature changes will alone result in an increase of net primary production, while radical changes will not. The optimum range is estimated as 18 °C - 25 °C, which means that the response of photosynthesis change decreases very rapidly to zero. This results in a situation in which substantial climate change drives a decrease in the terrestrial uptake of CO_2, thereby amplifying the initial warming process.

Temperature feedbacks affecting vegetation respiration and geophysical feedbacks due to water vapour, which amplify the greenhouse-gas induced climate change, are considered as critical responses of the environmental system to the disturbance of the equilibrium. The egalitarian, therefore, would estimate the value of Q_{10}^{res} at 4.0, the highest estimate found in the literature (Kohlmaier *et al.*, 1990). Due to the crucial role the egalitarian ascribes to water vapour feedback and the geophysical feedback due to clouds, climate sensitivity (λ) is estimated as 5.5,

which is likewise the highest estimate found in the literature (Dickinson, 1986).
Feedbacks and processes which will probably result from climate changes whereby the effect on imminent warming is still unknown are conceptualized as positive feedbacks. In the case of our selection this means that soil moisture changes, migration of ecosystems and geophysical feedbacks due to clouds are all perceived as substantial amplifying effects.

Management style

In order to prevent a full catastrophe in the long-term, drastic structural social, cultural and institutional changes are necessary, notwithstanding short-term disadvantages and costs, for example in economic sense. Possible policy measures aiming at such fundamental changes are to be found in strategy proposals of non-governmental organizations (NGOs) as Greenpeace (Leggett, 1990).

4.4.3. The individualist

World view

Consistent with the individualist's myth of Nature (Nature Benign), ecosystems are regarded as being resilient, i.e. the natural system will find a (new) balance. According to this view, climate change will be mitigated by known and unknown dampening feedbacks. Speculative negative feedbacks are therefore taken into account, whereas uncertain positive feedbacks are neglected or considered to have negligible impacts on the climate system.

If this individualistic perspective is applied to our selected uncertainties, we see that CO_2-fertilization and the direct and indirect effects of aerosols are perceived as important mechanisms in the natural response with its tendency towards stability. Due to these effects, any initial climate change would be curbed. Therefore, the fertilization factor (β) is estimated as 0.7, a value derived from experiments on individual plants in greenhouses (Goudriaan and de Ruiter, 1983). The indirect and direct dampening effects of aerosols are both considered as being substantial. The individualist's estimate of the direct effect more or less equals the highest scientific estimates, i.e $Q_{sox,\ direct} = 0.7\ W/m^2$, while the indirect effects are also perceived to be substantial, i.e. $Q_{sox,\ indirect} = 1.0\ W/m^2$.
According to the individualistic perception, temperature feedback effects on net primary production can be represented by a continuously increasing function instead of a parabolic function, reflecting implicitly the idea that species will be able to adapt to a changing climate without impairment of their productivity. In fact, productivity would increase due to optimal adaption to the new conditions.
Responses to climate change associated with soil moisture changes, migration of ecosystems and geophysical feedback due to cloud all have, according to the individualist, a dampening effect on any temperature increase. Combined with the individualist's moderate estimation of positive geophysical feedback due to water vapour, climate sensitivity is perceived as being low. Consistent with the lowest estimate of the IPCC (1990; 1992) the individualist's estimate as expressed in λ is 1.5.
The temperature feedback affecting respiration, a positive feedback, is seen as a process with minor impacts. Q_{10}^{res} is therefore represented by the value of 0.8, a low value which corresponds with lower moisture availability (Harvey, 1989).

Management style

A new equilibrium in the natural systems will provide new opportunities for smart individualists. According to the individualist, global climate change is therefore to be seen as a challenge and an opportunity. The minority of impacts that have negative effects on economic and social benefits will be cancelled out by technological innovations. To prevent negative impacts, financial and regulative incentives should provide a stimulus for innovative activities. In sum, no active climate policy is advocated.

4.5. Conclusion

The alternative model routes as described in this Chapter will be translated into model quantities and model relationships. Analysis of the CYCLES submodel aiming at the selection of the quantities and relationships reflecting the crucial uncertainties, and implementation of the alternative model routes in the CYCLES submodel will be carried out in the second quarter of 1995, which allows us to use these routes to render uncertainties associated with subjectivity and disagreement explicit within integrated assessment models addressing climate change.

The contents of this Chapter show that the selection criteria which we adopted (as described in Chapter 2) enable us to arrive at a plausible selection of crucial uncertainties as the comparison with the ranking compiled by Keith and Morgan (1994), based on the estimation of international climate experts, shows. In cases in which such a profusion of elucidated expert judgment is not available, the systematic evaluation of the magnitude, degree and time-variability will serve as a manageable heuristic and open the possibility of discussion with experts in other disciplines.

The case study of the climate change issue has, we hope, gone some way towards demonstrating that the cultural perspectives provides a useful framework with which to arrive at coherent and consistent interpretations of the uncertainties in the environmental system.

The perspective-based alternative model routes implemented in the CYCLES submodel and comparable models will allow us to broaden the scope of the scenarios and strategies in a manner which accounts for all perspectives. (Results of) simulation runs produced by integrated assessment models equipped with various model routes may be useful contributions to both the scientific and the policy debate on climate change.

5. CONCLUSIONS AND DISCUSSION

The present study describes a methodology designed to identify, illuminate and clarify uncertainties due to subjective judgment and disagreement among experts occurring in integrated assessment models. The proposed methodology uses perspective-based alternative model routes to enable perspective-related uncertainties to be analysed systematically and quantitatively. With the cultural perspectives as heuristic device, alternative model routes provide consistent and coherent chains of interpretations of crucial uncertainties.

We applied the methodology to the population issue and the climate change issue to assess the usefulness and limitations of this kind of uncertainty analysis for both the human and the environmental system. The proposed selection heuristic, whereby the uncertainties are ranked in order to arrive at a manageable and workable set of crucial uncertainties, proves as a useful approach, in the case of the climate issue in which a large number of uncertainties related to subjective judgment and disagreement exists, in particular.

Alternative model routes have been implemented in the fertility submodel of TARGETS. Preliminary experiments show that differences in future projections can be motivated and explained by differences in the interpretations of the uncertainties, instead of merely arriving at minimum, maximum and best-guess values. The simulated historical paths may lead to the conclusion that perspective-related uncertainties provide room enough for fundamentally differing explanations. Sensitivity analyses are needed to evaluate whether parameters not significantly varying in the various model routes dominate the model outcomes, which should account for the similarities in the historical trajectories.

The evaluation of uncertainties by reference to risks associated with response strategies enables us to assess which uncertainties due to subjective judgment and disagreement among experts are most relevant for the policy debate. The alternative model routes thereby provide a tool to recognize the key-uncertainties with regard to policy strategies, which insights might be used to (re)establish the research agenda. Experiments with models equipped with alternative model routes provide an opportunity to develop scenarios in a coherent and consistent way.

The main problems arising in the methodology of alternative model routes involve the need to interpret the cultural perspectives, which is in itself a subjective activity. It is therefore important to elucidate such interpretations when applying alternative model routes. Criticism of Cultural Theory often employs the argument that it is a Western perception of culture. It is therefore important not to be satisfied with Cultural Theory as such. It is a highly aggregated typology which makes interpretation difficult, and has mainly been developed by West-European and American scientists. We need to find ways in which to specify the cultural perspectives, or to enlarge the spectra in the event that the approach proves not to cover the scope of perspectives in the oriental and "Southern" parts of the world. It is therefore important to discuss the alternative model routes with scientists and policy-makers all over the world, thus creating a process in which the cultural theory is both refined and improved as well as lending itself as heuristic device in the uncertainty analysis of alternative model routes.

In this paper, we have described alternative model routes for the climate part of the CYCLES submodel in a narrative. These model routes will be implemented in the second quarter of 1995. Moreover, alternative model routes will be developed and implemented in all submodels of TARGETS submodels, which will enable integrated analysis of uncertainties in future projections. Such integrated experiments will be of use for, for example, the United Nations Environmental Programme (UNEP) and the Human Dimensions of Global Environmental Change Programme (HDGECP).

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