AN EVOLUTIONARY INTEGRATED MODELING APPROACH: A CASE STUDY FOR CLIMATE CHANGE

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Abstract

Addressing global change demands an integrative consideration of interactions between humans and the environment on a world wide scale. An assimilative integrated system approach seems to be appropriate for investigation of this complex global problem. In this paper an integrated modeling approach is proposed that is based on an evolutionary view on global change. A case study is worked out where images of the future using a multi-agent model are assessed, and where agents differ in their world view and thus also in their preferred management style. The perspective of agents may change due to new information they derive from the system. A simple model is constructed to illustrate the consequences of this approach on climate change scenarios.

1 Introduction

Scanning the future raises the problem of assessing inherently unpredictable and therefore highly uncertain phenomena. Policies are often made in the face of ignorance about the actual dynamics of the system. This ignorance may stem from the fact that the requisite knowledge lies in the future (De Greene, 1993). Needless to say that policies are value-oriented, that values change over time, and that knowledge is never perfect at any given time.

Two examples of outdated predictions are the following. About two centuries ago, Malthus (1798) regarded food production as a land-limited resource that could not possibly be increased quickly enough to keep in pace with a growing population. Malthus pessimistic expectation did not came true due to a sharp increase in agricultural productivity from technological progress. Meadows *et al.* (1972) presented the warning that the ongoing depletion of resources would result in a world wide collapse of the world economy. The oil crises of the seventies which increased energy efficiency and due to many new discoveries of reserves, resource depletion became a less urgent issue (Meadows *et al.*, 1990). The scenarios became not reality

for two possible reasons: (i) humans adapted their behavior; (ii) the scenarios where too pessimistic about the innovate capability of humans and the capacity of nature.
In this paper a modeling paradigm will be presented which tries to integrate adaptive behavior of human activities with the possibility of different world views. Proposed is to focus on the problem of human-induced climate change, because this problem is not without controversies and also since it has important international policy implications for the coming years.

2 An Evolutionary Integrated Modeling Approach

One of the approaches to scan the future is the use of integrated assessment models. These models are scientifically based models to support policy making and which describe the human and the environmental system on a global scale (Rotmans and Dowlatabadi, 1996). They do not describe the complex system in detail but rather use simplified versions of specialist models such the model can be used iteractively to compare the consequences of various scenarios.
The present generation of integrated assessment models is mainly based on a mechanistic paradigm. Mechanical causality, expressing overarching natural laws explains all things. The increasing pressure of human activities causes that the environmental system is forced out of the pre-industrial “natural”equilibrium. This disequilibrium is thought to be a threat which can be fended by reducing the pressure to a level such that the system finds a new equilibrium. According to Allan (1990) equilibrium models are a most unlikely basis for anticipating the future, particularly with respect to change. Instead of discussing idealized equilibrium systems, and focusing on stability, we must try to understand instability and change. Mechanical systems are only capable of “functioning” within their fix boundaries not of evolving towards new behavior. Other than natural systems, mechanical systems are unable to restructure themselves or insert new relationships.

Scanning the future of the global system for the next century without considering the ability of systems to adapt, may generate a misleading picture of the impact of changes. Nature, people and economies are suddenly now co-evolving on a planetary scale, each affecting the others in such novel ways and on such a large scale that large surprises may overwhelm the adaptive and innovative capacities of people (Holling, 1994).

The question of sustainable development is therefore how to stimulate a sustainable co-evolution of human activities and environmental change. A recent development in modeling is the use of complex adaptive systems. Such a system is complex in the sense that it consists of a network of interacting agents, it exhibits a dynamic, aggregated behavior that emerges from the individual activities of the agents. Furthermore, the behavior of the system can be described without detailed knowledge of the behavior of the individual agents (Holland and Miller, 1991). Agents in such a system are adaptive if their actions can be assigned to a fitness value, and the agents behave so as to increase these values over time. A complex adaptive system is a network of adaptive agents such that the environment of each adaptive agent includes other agents in the system.

Research with respect to sustainable development often merge disciplines from social science, economics and ecology. Although many attempts are made to come to an integrated approach it is my opinion that they all fail by considering only one disciplinary modeling paradigm. When modeling the global system we may distinguish various levels of modeling may be distinghuished. De Vries (1994), for example, distinguishes three levels. At the first level he assumes the physical stocks and flows, which constitute the observable reality. The next level maps the behavioral and informational structures which govern human interference in the underlying physical environment. The third level are the values, beliefs and ideas about the system which we here share under the term perspectives, and those reflect and motivate people's behavior.

Based on De Vries (1994) three interwoven levels are distinguished in constructing an integrated modeling paradigm for global change (Figure 1). The first level consists of the physical laws. The flow of minerals through environmental reservoirs can be described satisfactory by sets of differential equations, as can with other issues such as atmospheric chemistry, hydrology and thermodynamics. In my objective to study global change I may consider a time horizon of about one century. Given this assumption I believe it is permitted to assume that the mechanisms and structure if the physical system remain unchanged. Of course, the flows between the reservoirs may change due to living and non-living components of the Earth system, but to describe this part of the system, a deterministic description is likely to be satisfactory.
The second level comprises the living part of the Earth system. At this part of the global system, structural and mechanistic change occurs frequently within the

considered horizon. I consider three fields within this part of the system: economy, describing the interactions between agents who maximize their utility by exchanging resources, labor, capital and the environment; sociology, describing the behavior of individuals in groups and behavior between groups; ecology, describing the behavior of organisms in relation with its environment. By assuming that agents have no perfect knowledge and do not act purely rational, interactions between agents results in unpredictable behavior at the macro scale. It appears that such a system might well be described by the concepts of complex adaptive systems. At the thirds level I assume the driving forces to the behavior of agents; their needs, norms and values. I propose not to describe this level in mathematical formulas, although describing the behavioral "rules" at the second level might be clarified by conceptual models of the third level. Using the Cultural Theory (Thompson *et al.*, 1990) in representing different management styles and world views is an example of the use of such a conceptual model, which is briefly discussed in the next Section.

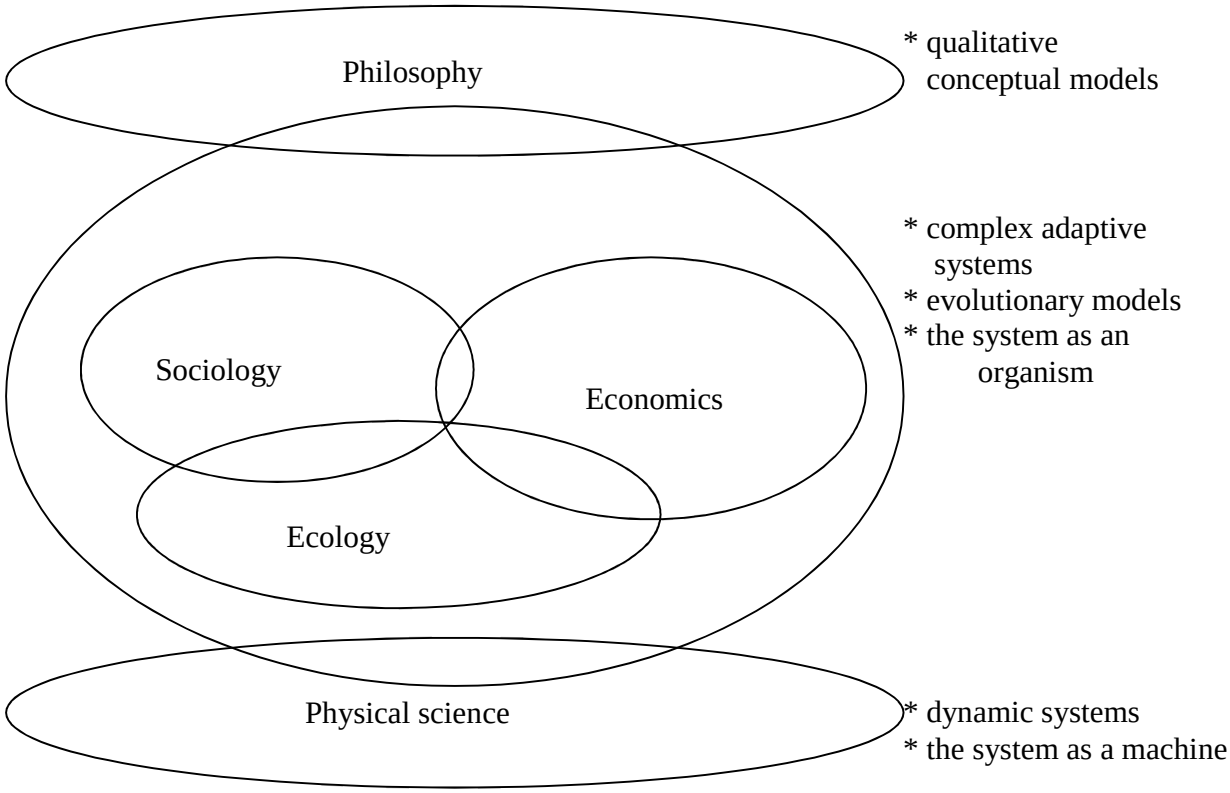

figure 1 An integrated modeling paradigm.

3 A Case Study: The Battle of Perspectives

The aim of the "Battle of Perspectives" is to simulate changing world-views of agents which are assumed to change the behavior of those agents (Janssen, 1996a). While I implemented a version of the concept for the climate change problem the agents represent abstract images of decision-makers on an international level. The dominant perspectives among the agents evolves over time and is fed by the agents' observation of the system. In a competitive environment in which adherents to a variety of perspectives all claim to provide explanations, agents try to find the best possible explanation of the observations.

In this paper the agents differ in their world views and therefore in their preferred management style. Their success in explaining the information derived from the system determines the fitness of the agents' world view. The better the agents' world view explains observed behavior the higher the chance that it will not change its world view. On aggregate there is a trend to change to the world view which explains the observations in the most likely way. Note that the agents represent decision makers, instead of arbitrary individuals. As a framework to classify possible world view we assume three active perspectives based on Thompson *et al.* (1990) and Rayner (1991):

- Hierarchists: Humans are born sinful, but can nevertheless be redeemed by virtuous institutions. Nature is stable in most circumstances, but can collapse if it crosses the limits of capacity. Therefore control is advocated as management style.
- Egalitarians: Believe that human beings are born good but also highly malleable by evil institutions. nature is highly unstable, and the least human intervention may lead to complete collapse. A preventive management style is preferred.
- Individualists: Humans are self-seeking and unmalleable. Nature provides abundance of resources, and is believed to remain stable under human interventions. An adaptive management style is advocated.

I use the active perspectives as extremes of a continuum which is used to describe all possible points of world views. The agents perspectives are laying in this triangle and swarm over the continuum fed by the information from the system. These changes are simulated by using genetic algorithms (Holland, 1975; Goldberg, 1989), a simulation tool based on the concept of the survival of the fittest.

The model

A simple dynamic system describing the economy and the climate system and their interactions is used to illustrate the "Battle of Perspectives" (Janssen, 1996b). This model is based on existing economy-climate models such as those found in Nordhaus (1992), Hammitt *et al.* (1992) and Lempert *et al.* (1995).

The "Battle of Perspectives" model consists of three model versions for each of the above world views by taking into account controversies about climate sensitivity, technological improvements, mitigation costs, and damage costs due to climate change. The egalitarian, for example, assumes a high climate sensitivity, high damage costs, low technological development and low mitigation costs. For the management styles we assume different strategies for investments and reductions of emissions. The individualist, for example, assumes a strategy that maximizes economic growth and so that emissions are reduced only if a certain threshold of economic damage is exceeded.

Experiments

50 agents are included in the "Battle of Perspectives". By way of a sensitivity test, the three different model versions for various initial mixes of perspectives are analyzed. For each experiment a different perspective dominates. In order to analyze the consequences of the various perspectives among agents, we performed the experiments for three sets of assumptions of the global system according to the perspectives. For each experiment 100 runs are performed for which the average values are depicted in Figure 2. Between the model versions significant differences are found, also when the spread of outcomes due to the stochastic characteristics of the genetic algorithm is included (see Janssen 1996a,b).

In the event of the world functioning according to the egalitarian world view, economic the emission growth stabilize on average in the coming decades and decrease to a level below half the present amount of emissions. However, this reduction policy can not avoid that the global mean temperature increases with about 2.5 ^{o}C in the coming century. This increase would be lower if one assume a pure egalitarian utopia. However we did not do so, but took explicitly into account the "Battle of Perspectives". In the hierarchistic world, the average future scenario of emissions stabilize at a level of 50% above the prsent amount, and the global mean temperature rise up to 1.5 ^{o}C above present. In the system which functions according

to the individualist, the climate system will not be sensitive to carbon emissions leading to a continuing use of emissions, up to 10 GtC above present.

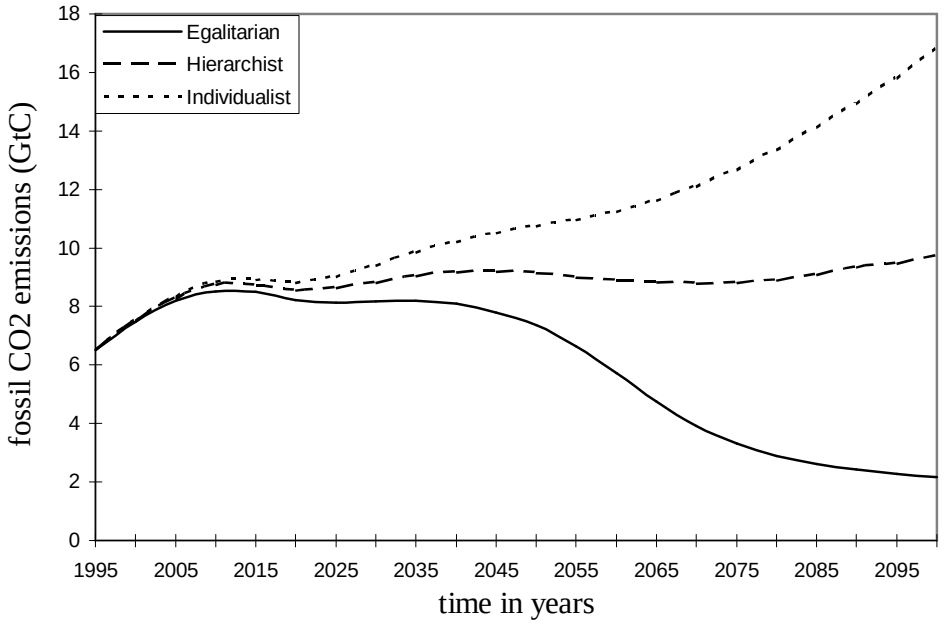

figure 2: Average CO_2 emissions according to different views on the functioning of the global system

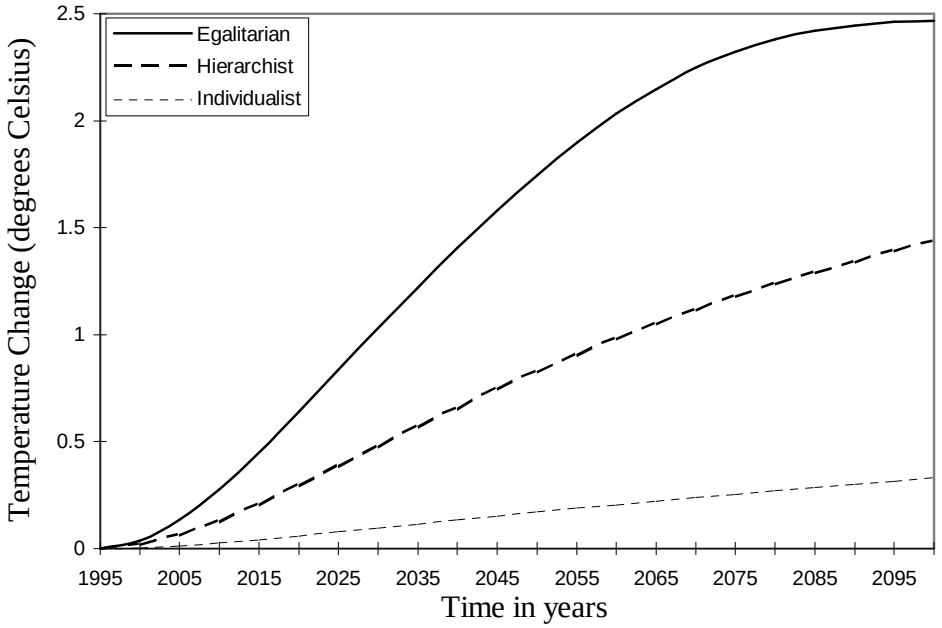

figure 3: Average temperature increases according to different views on the functioning of the global system.

In the exploratory experiments, agents seem to be adapt to changing insights in the functioning of the global system. This is not surprising because the agents were "modeled" accordingly. But suppose that the agents become confronted with a surprise. Image a world, in which serious warming may occur due to human intervention in the global system. Suppose furthermore that this is a world in which the egalitarian perspective dominates at the start and that observed global mean temperature is masked by an additional cooling effect. If this mask falls off in the middle of the next century, confronting the agents with a surprise.
In such a world, a cooling surprise would lead to a slowing-down of emission reduction due to great dominance of the hierarchistic and individualistic perspectives (Janssen 1996a,b). This results in an additional increase of about 1°C by 2100, although this increase is not recognized before the middle of the next century. This experiment illustrates that a delayed response not only leads to a later reduction of emissions, but also that due to a lock in of an individualistic management style the emission reductions are slower implemented leading to an extra delayed effect.

4 Conclusions

The "Battle of Perspectives" is meant as an academic illustration of possible use of evolutionary modeling in order to include simulations of human behavior within integrated assessment modeling. The presented approach simulates the response of similar agents to the changes in the system. Such responses are influenced by the world-views and resulting management styles of the agents. Observations of the global system may change the perspectives of the agents in the coming decades. The results demonstrate the potency of a different concept in scanning the future. Taking the notion of learning and adaptation into account may lead us to new kinds of images based on the assumptions of the global system and the decision rules adopted by the agents. This approach may prove to enhance insights into possible images of the future.

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