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Models at the interface between science and society: impacts and options

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Within the CLEAR project a new approach to integrated assessment modelling has been developed for the participatory integrated assessment of regional climate change involving citizens' focus groups. The climate change decision problem was structured by focusing separately on climate impacts and mitigation options. The attempt was made to link the different scales of the problem from the individual to the global level. The abstract topic of climate change was related to options on the level of a citizen's individual lifestyle. The option of a low energy society was emphasised in order to embed the climate change decision problem in a wider range of societal concerns. Special emphasis was given to the characterisation and communication of uncertainties. The chosen approach allows different kinds of uncertainties in one framework to be addressed. The paper concludes with a summary of the experience made, and recommendations for the use of models in participatory integrated assessments.

Keywords: participatory integrated assessment, climate change, low energy society

1. Introduction

In dealing with environmental problems, models play an ever increasing role, in particular in the emerging field of integrated assessment (IA). IA has as its stated goal to integrate the knowledge from different disciplines about an environmental problem along the whole chain of causes and effects to provide useful information for decision-makers. The construction of large integrated assessment models has been the prevalent approach to achieve this goal. As far as the problem of climate change is concerned, a number of integrated assessment models have been produced up to date (e.g. [1–3]). Most models address the climate change problem at the global scale. Many are based on the so-called PSIR philosophy, in which a model includes the causal sequence and feedback along the sequence of pressure (e.g., fossil fuel burning and carbon dioxide production) → state (e.g., global climate – temperature) → impact (e.g., sea level rise and its associated damages) → response (e.g., mitigate climate change by introducing a carbon tax). Such models attempt to portray the complicated network of feedback and causal relationships between natural, technical and socio-economic systems. They allow, for example, the investigation of the efficiency of political measures and potential unexpected feedback effects. Such model building exercises yield simulation results that may then be used in political debates and also be communicated to the public. Much emphasis has also been placed on accounting for uncertainties and elucidating their importance for decision-making. Disciplinary scientists may learn more about the relevance of their results and the importance of their assumptions in an integrated context. As far as the interface between science and society is concerned, these models serve in general as a means for a unidirectional transfer of scientific knowledge to the public. Their use in policy processes has been limited up to now [4,5].

Integrated assessment modelling and participatory integrated assessment (PIA) developed for a considerable time rather independently [3,5]. PIA assesses a broader context of societal decision-making. Human participants are interacting with one another and with expert knowledge in a structured and decision-oriented setting. The integration comprises both expert and local knowledge.

However, more recently, IA models have increasingly been used in participatory settings (Jaeger et al. this volume, [6,7]). In PIA stakeholders and decision-makers actively participate in the process of integration by contributing their knowledge and assessments. The process of integration comprises thus the integration of different kinds of knowledge. This is particularly important at the regional scale since it has become increasingly evident that decisions related to climate change will be made at the regional scale and will be driven by short-term considerations that are not directly related to climate change [4].

What is required is a new approach to developing appropriate model frameworks for a participatory integrated assessment at the regional scale. Such an approach has to take into account that such models should be part of, and even structure, a dialogue between science and society. This idea must be reflected in the whole process of model building, design and application. In the CLEAR project, the building of an integrated assessment information and model platform was, on the one hand, embedded in a research process comprising a number of disciplinary projects. On the other hand, citizens were included into the model building process at an early stage.

2. Integrated assessment of climate change at the regional scale

Most regional analysis of climate change have been limited to considering response options for adaptation in order to reduce the adverse effects of the impacts of climate change. This is not astonishing since the decision problem, if posed in a formal way, is not solvable as far as mitigation options are concerned.

The PSIR approach is not applicable to assess mitigation options at the regional scale because the causality along the sequence pressure (regional) → state (global) → impact (global with regional manifestations) → response (regional) is undefined. There is no direct relationship between individual regional action and global climate change. If Swiss citizens reduced their energy consumption to one third of the current value they could not prevent a regional increase in temperature and the disappearance of glaciers in the Swiss Alps brought about by global climate change, unless other countries would follow. If one assumes further that any measures targeted at mitigation, such as a carbon tax, are always associated with additional costs, it is difficult to justify any action at the regional scale. It is argued that costs (e.g., increased energy prices) are experienced at the regional scale whereas benefits (reduction in damage arising from climate change) are shared by all countries (OcCC, 1998). This type of argumentation is based on a cost-benefit approach to address the climate change decision problem in which mitigation costs are justified by the prevention of damages. Cost-benefit analysis provides a convenient and convincing framework to structure the decision problem and to structure the exchange between the natural sciences determining impacts and the social sciences viz. economics casting these impacts and damages into quantitative monetary terms.

The applicability of cost-benefit analysis to deal with the climate change problem has been questioned (e.g. [8]). On the one hand, the choice of the discount rate is crucial for such an analysis and it exists no consensus about the appropriate rate of discount. On the other hand, the numbers for both costs and damages are highly uncertain. They depend on a range of assumptions about the behaviour of natural and socio-economic systems, assumptions that are not unambiguous.

Our approach to integrated assessment is based on a perception of decision-making that invokes processes of social learning. Social learning is defined here as the mutual shaping of expectations of the involved groups. The shaping of expectations depends on institutions. In the light of the new approaches of institutional economics, an institution may be defined very broadly as shared rules of human conduct. For example, while driving on a road one expects other drivers to respect the red light and to stop. Without such shared rules of conduct, living in a society would be impossible. Some institutions (laws) are enforced by legislation (e.g., traffic regulations). Others (customs) are shared by the members of a society and evolve and change in a social setting (e.g., shake hands for welcome). Rules enable individuals to form expectations concerning the actions of others.

As far as the climate change problem is concerned, a process of social learning may encompass the improvement of the dialogue between science and society, scientists and citizens in particular. Scientists hold expectations about the information required by society and the societal perception of climate change as a problem. Citizens hold expectations about the type of factual information provided by scientific experts.In particular, the communication of uncertainties is crucial in such a dialogue.

On the other hand, social learning may involve the shaping of mutual expectations among different social groups, in general. However, consumer preferences, subjective beliefs about the nature of climate change and the perception of business opportunities may change in such a dialogue. The introduction of a new product, for example, depends on the expectations about the market volume. The price may depend on the number of sales, decreasing with the number of sales increasing. Such decisions involve elements of chance. Decision-making may thus be viewed as a collective search process in opportunity space. Since both individual and collective rationality are bounded, the search process is a local one; its direction depending on information, prior experience and collective expectations. Uncertainties are also crucial here since they determine the degrees of freedom within such an opportunity space.

Based on the previous considerations, one can now deduce the following requirements for models for a participatory IA process at the regional scale:

- build interactive models that allow subjective assessments of risks and options;
- convey all uncertainties that emphasise also the limits of scientific knowledge and convey the degrees of freedom for choice;
- embed the climate change problem into a wider range of societal concerns.

3. The CLEAR platform

To meet the requirements for a PIA at the regional scale a new type of model and information platform was developed. The CLEAR platform comprises three different components:

- IMPACTS dealing with causes and impacts of climate change at regional and global scales. A major emphasis is placed on the presentation and communication of different kinds of uncertainties [7]. IMPACTS emphasises the regional scale and a time horizon of 30–40 years. However, it provides also information about impacts at the global scale.
- OPTIONS dealing with options to mitigate climate change at different levels of societal organisation. It emphasises the option of a low energy society that embeds the climate change decision problem into a wider range

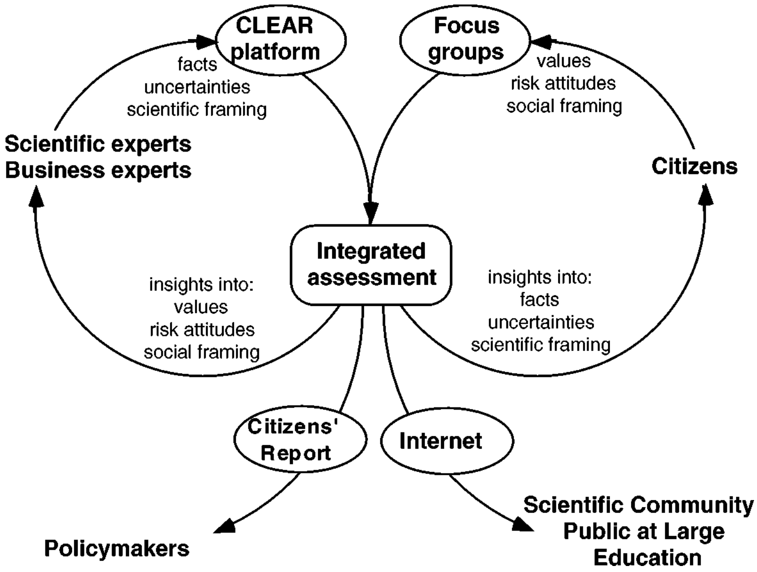


Figure 1. Process of integration in which the CLEAR platform was produced and applied.

of societal concerns. OPTIONS emphasises the national scale from the presence to a time scale of up to 40 years. It attempts to embed individual action into the national and even global perspective.

- The personal CO_2 calculator allowing a citizen to explore options at the level of his individual lifestyle [9].

It is evident, that impacts and options are not directly linked and evaluated within a formal framework. The integration and the process of assessment take place in citizen focus groups that were specifically designed for integrated assessment [10,11]. Figure 1 gives an overview of the participatory process of development and application of the CLEAR platform and the integration of expert and local knowledge. Scientists and business experts were actively involved in the process of data gathering and the subjective assessment of the state of the art knowledge on climate change. The ICITs were used already at an early stage in test focus groups with citizens to account for both the "supply" and the "demand" driven components of model development. The CLEAR platform was used in citizen focus groups to discuss climate risks and options. The overall assessment of the focus groups was summarised in so-called citizens' reports (see Jaeger et al., this volume). The CLEAR platform is also available via Internet for the scientific community and the public at large. This platform has further been used in education at high school and university.

To make a clear distinction to the established integrated assessment models used for simulations we decided to call these hybrids between models and information systems ICITs, computer-based interactive citizen information tools [7]. Their purpose is to make decision-oriented expert knowledge on complex problems accessible and utilisable for citizens. ICITs can be composed of a combination of deliberative expert judgements and formal simulation models. The contents may have the form of texts, graphs, images, animations and interactive simulation models and calculation tools. They provide structured, interactive and descriptive access to this expert knowledge. The graphical user interface of ICITs is targeted towards citizens with no expertise in using computers.

In contrast to IA models, ICITs are not used to make overall assessments of climate change in a formal framework based on simulation models. Therefore, ICITs can more easily be complemented with qualitative information and can illustrate conceptual uncertainties. They convey qualitative, quantitative and conceptual expert knowledge that is relevant for citizens in their assessment of the problem at hand.

ICITs provide easy to handle user-interfaces for lay persons. They are based on state-of-the-art graphical user interfaces and are self-explanatory to a large extent. As the main functionality of ICITs is to give citizens structured access to a broad range of various information, we relied heavily upon the concepts of hypermedia systems and especially the World Wide Web to build the first ICITs for IA-focus groups.

The approach chosen allows aspects of the climate change decision problem to be linked across scales in time and space – short- and long-term, regional and global. The goal is to embed the highly abstract climate change problem into a citizen's everyday life without losing the relation to the global and long-term. The personal CO_2 calculator has the most immediate link to the individual citizen and his present life and shows the available options for each individual in his daily life style irrespective of any costs. This way, the importance of life style choices for energy consumption become very tangible. The CO_2 calculator addresses the global scale and ethical concerns by providing comparisons to life styles in other parts of the world [9].

Uncertainties are crucial when making an assessment of risks and options. The higher the uncertainties the more important are subjective perspectives for making an assessment [12]. We did not attempt to implement scenarios for given perspectives into the CLEAR platform as was done in the TARGETS model [3]. Our approach allows to address uncertainties of different kind that can hardly be handled all in a simulation model. The user can make a subjective assessment based on his own perspective.

4. Characterisation of impacts and uncertainties

IMPACTS deals with causes and impacts of climate change at regional and global scales. Figure 2 gives an overview of the hierarchical organisation of the contents. The different sections comprise:

- Climate scenarios
  - At the global scale a causes model allows a whole range of scenarios for global temperature to be constructed by varying the driving forces.
  - At the regional scale the user can switch between a range of scenarios that visualise the change of temperature and precipitation in time and space.
- Impacts – regional and global for two scenarios – weak and strong climate change
  - The most important impacts at the global scale are described.
  - Regional impacts are subdivided into effects on the natural environment, on the likelihood of natural disasters, on different sectors of the economy and on human life.
- The information provided allows a subjective assessment of impacts along different dimensions:
  - monetary risks that can in principle be quantified (e.g., damage due to extreme weather events, loss in economic sectors, such as tourism);
  - risks to personal health and safety (e.g., natural disasters, migration);
  - risks to the environment that is part of cultural heritage (e.g., glaciers);
  - impacts at global scale that may affect Switzerland (e.g., financial crises, migration, profit from economic damage in other parts of the world);
  - impacts at global scale that pose moral problems (e.g., poverty, catastrophes).

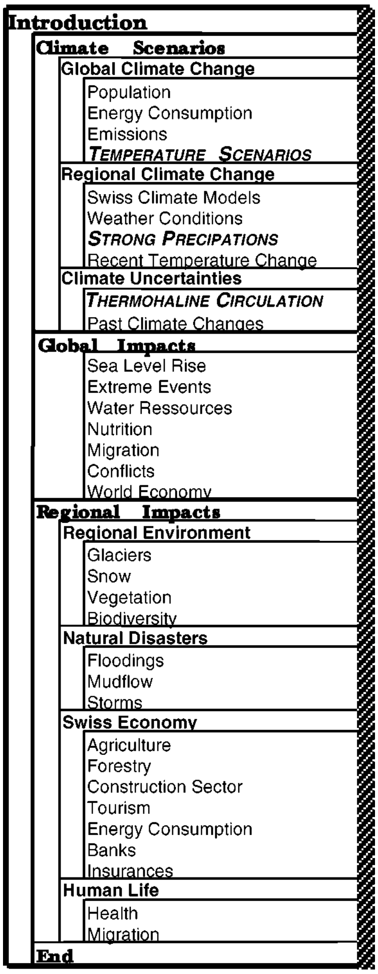


Figure 2. Overview of IMPACTS and its hierarchical structure of layered factsheets. The three topics that are discussed in more depth to exemplify the different kinds of uncertainty that are addressed in the text are highlighted: temperature scenarios, strong precipitations, and thermohaline circulation.

The perception and valuation of impacts depends crucially on uncertainties. The approach chosen allows different kinds of uncertainties to be addressed. This is exemplified by three models representing different types of uncertainty that can hardly be accounted for simultaneously within a conventional simulation framework. Each of these models is embedded in a context of information. The uncertainties to be discussed refer to:

(1) the range of scenarios for a gradual increase in temperature;

(2) changes in the likelihood of extreme events and their consequences;

(3) low probability, high risk events. Abrupt changes in climate arising from non-linear dynamics of the climate system and threshold effects.

In the following, these three different kinds of uncertainties are discussed in more detail.

4.1. Range of temperature scenarios

The most prominent feature of climate change is an increase in global temperature. However, depending on the assumptions on the dynamics of the driving forces (e.g., economic growth, energy consumption), the distribution of carbon dioxide in the atmosphere and the sensitivity of the climate on increased atmospheric carbon dioxide concentrations, different scenarios can be obtained. The causes model allows the user to explore the consequences of different assumptions on the target variable global temperature (figure 3). The model provides a restricted set of plausible options allowing the user to derive the whole range of temperature scenarios from 1.5 to 4.5 °C discussed by the IPCC

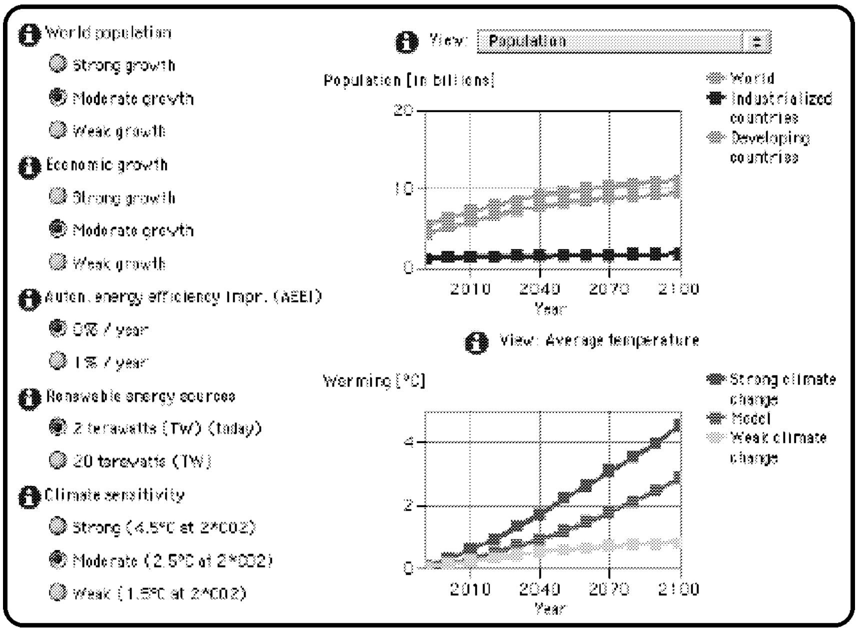


Figure 3. The causes model allows the user to explore the uncertainties in the driving forces for the change of average global temperature. The user can define own scenarios (violet curve). The scenarios for weak (yellow) and strong (red) climate change are always shown as reference.

for a doubling of CO_2 concentrations [13]. Furthermore, the user can find out that the assumptions regarding the sensitivity of climate have the largest effect on global temperature. It has been discussed what this range of temperature scenarios has to signify. Does it represent a probability distribution in which the best guess scenario should be located somewhere in the middle? Or should the probability distribution be represented by a rectangularly shaped interval? The general opinion is rather that the range reflects the whole set of the combination of independent assumptions on climate change in which the shape of a probability distribution is largely unknown (see [14]). To derive climate change impacts we therefore decided to choose two scenarios that are located at the boundaries of the total range – weak and strong climate change (figure 3).

For a given global temperature scenario, regional temperature change is associated with additional uncertainty. Because of the extreme uncertainties that increase in the sequence global temperature change–regional climate change–regional impacts–any probabilistic statements at the level of regional impacts are not meaningful. The description of regional impacts for each scenario was therefore expressed in a set of qualitative statements derived from subjective assessments of experts on the topic [7]. For each impact, the user can explore the possible manifestations in the weak and strong climate change scenario. Additional uncertainty may enter since impacts may be contingent on assumptions that are independent of climate change (e.g., agricultural policy).

4.2. Extreme events

Changes in the likelihood of extreme weather events are of major interest, in particular in the Alpine region where natural disasters, such as mudflows, are a well-known phenomenon. An increase in the annual average precipitation is expected to lead to an overproportional increase in heavy precipitation events ([15] and Schär et al. this volume). However, it is difficult to give a quantitative estimate on the impacts of such changes. On the one hand, the damages caused by extreme weather events are determined by a number of other factors, such as demographic development and the choice of settlement areas. On the other hand, it is difficult to provide statistical evidence for changes in the probability distribution of extreme events and potential statistical correlations (e.g., correlation between an increase in extreme heavy precipitation events and an increase in the damages paid by insurances). The user may explore the phenomenon with the help of a simple calculator (figure 4). As background he can either choose a scenario from a GCM or make his own scenarios. The changes in the frequency of strong precipitation events are calculated and immediately displayed. How can the user now explore the potential threat arising from extreme precipitation events?

The user may follow a guided path through IMPACTS that links causal relationships in a qualitative fashion: he starts with the simple calculator that allows him to explore the relationship between an increase in average precipitation and the changes in the distribution function of precipitation events (figure 4). A rise in the likelihood of extreme events increases the likelihood of mudflows. The user may thus visit the factsheet on mudflows in which the phenomenon is explained and a video gives a very lively impression on the phenomenon itself. Finally, a factsheet on insurance companies gives information about the costs from damages paid by insurance companies in recent years to compensate damages arising from natural disasters. The data provided and the qualitative assessments of domain experts leave the final interpretation of the risk to the user's subjective judgement.

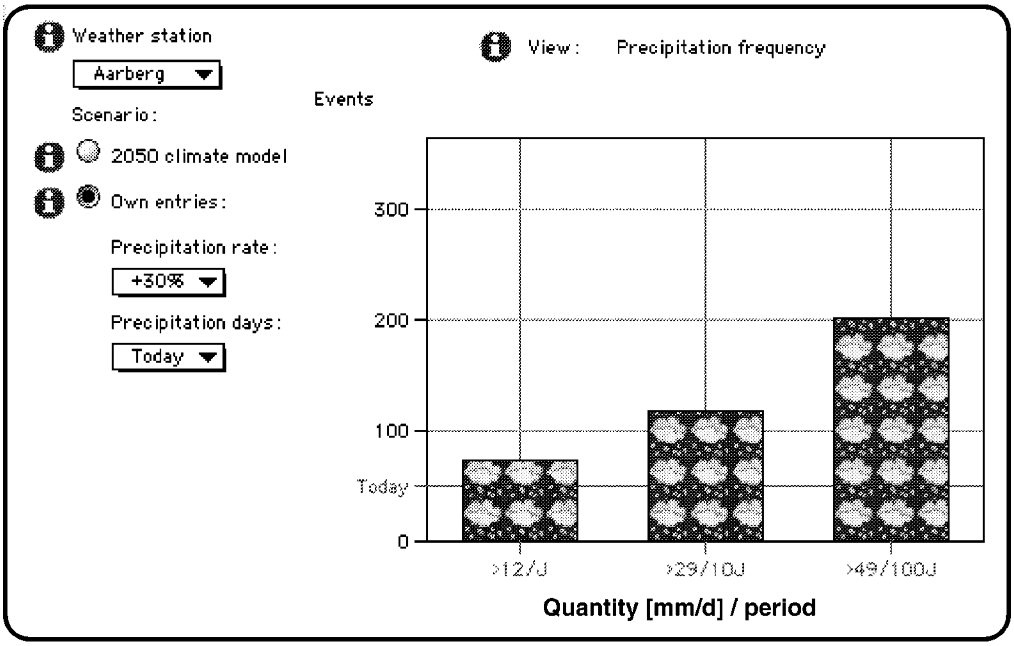


Figure 4. Model that calculates changes in the frequency of strong precipitation events at a certain location as a function of changes in the mean annual temperature and in the number of precipitation days. It is evident that for a 30% increase in precipitation, the likelihood for an extreme precipitation event of more than 49 mls per 100 years increases by 200%.

4.3. Abrupt climate changes

Regarding climate uncertainties, one of the most difficult issues to communicate in a responsible fashion are low probability, high risk events. The most prominent example is given by a slowing or even shutdown in the thermohaline circulation of the North Atlantic that may result in abrupt climate changes (Appenzeller et al., this volume). Reconstructions of historical climate from paleoclimatological investigations provide evidence for abrupt climate changes in the past. Such reconstructions provide evidence for a drop in temperature of several degrees over a few decades. The most likely cause of such changes is an increase in the freshwater input into the North Atlantic and a subsequent reduction or even shutdown of the thermohaline circulation. IMPACTS contains a simple model of the phenomenon combined with historical evidence on past climate changes. The model allows the changes in the thermohaline circulation of the North Atlantic to be explored (figure 5). The user may investigate the relationship between the time course of carbon dioxide concentration characterised by the final target level and the rate on how fast this target is reached, as well as the strength of the thermohaline circulation. The model is a simplification of the more complex model by Stocker and Schmitter (1997). It comprises essentially a non-linear response mechanism for the adaptation of the thermohaline circulation to a change in carbon dioxide concentration. A parameter allows high or low climate sensitivity to be accounted for.

A shutdown of the THC may have a considerable effect on the climate in Europe. To receive an impression on what such a climate change may imply the user may visit a fact sheet on past climate changes reconstructed from paleoclimatological investigations (figure 6).

The assessment of low probability, high risk events is highly perspective dependent. Up to now, the IPCC has been quite reluctant to report on such phenomena since it is not trivial to do so in a scientifically sound and responsible fashion. Sir John Houghton, chairman of the scientific working group of the IPCC, wrote in a letter [16]: "*There are those who home on surprises as their main argument for action. I think that is a weak case. No politician can be expected to take on board the unlikely though possible event of disintegration of the west Antarctic ice sheet. What the IPCC scientists have been doing is providing a best estimate of future climate under increased greenhouse gases – rather like a weather forecast is a best estimate. Within the range of possibility, no change of climate is very unlikely. Sensible planning, I would argue needs to be based on the best estimate, not on fear of global catastrophe or collapse*."

The situation has started to change since the previously more fragmented and contradictory nature of scientific evidence has started to become more coherent. Nevertheless, for such phenomena it is quite difficult to develop a consensus view that is still the preferred attitude of the IPCC. However, it may not be desirable to attempt the achievement of consensus. Why should there not remain a certain level of disagreement among scientific experts if complex issues are under debate? More emphasis should be placed on eliciting subjective expert opinions and on including them into the IPCC process, into IA models and into the public debate about climate change in general.

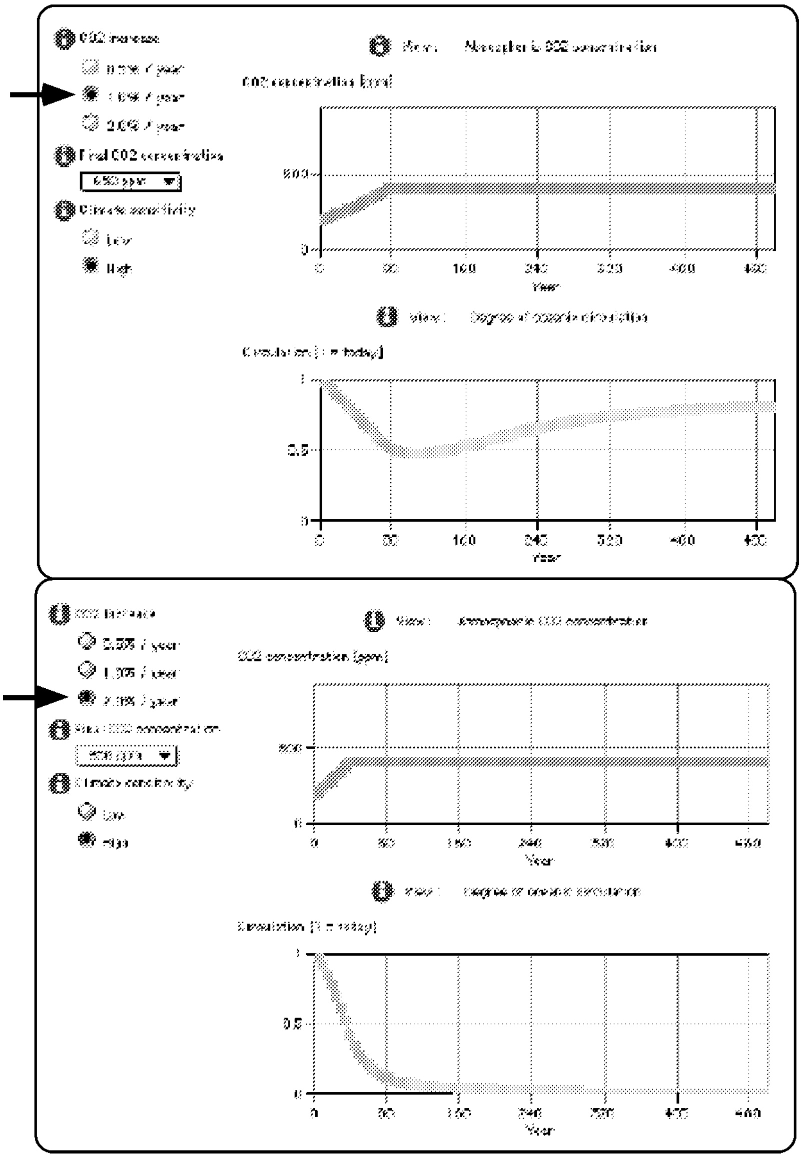


Figure 5. Simple model to explore the effect of a change in carbon dioxide concentration on the strength of the thermohaline circulation (THC). The chosen scenarios show that the shutdown of the THC does not only depend on the target level of CO_2 but also on the rate at which the target is reached.

5. Characterisation of options and uncertainties

Options to mitigate climate change are dealt with in the personal CO_2 calculator and in OPTIONS. The attempt is made to embed individual choice into options at the national and even global scale. The personal CO_2 calculator is a spreadsheet like calculator that allows the effect of behavioural and technological lifestyle choices to be explored [9]. OPTIONS makes an attempt to link the scales of the individual and the society as a whole. To do so, individual choice is detached from personal lifestyle by including the effects of individual choice into the energy consumption of Switzerland. Energy scenarios for Switzerland include, for example, the average number of cars per person and trend scenarios on how this number is expected to change on average. Users making individual choices are thus in the role of a typical representative of all Swiss citizens. This triggers discussions regarding lifestyles that could be shared by the majority of citizens, discussions about the links between the responsibility of the individual making lifestyle choices and options and measures at other levels of societal organisation, such as energy taxes or subsidies for energy saving technologies. Figure 7 gives an overview of the major components of OPTIONS.

In particular OPTIONS includes the following modules:

- A model for global dynamic energy scenarios allows the influence of different factors on energy consumption and carbon dioxide emissions to be investigated. One can explore that a stabilisation of atmospheric carbon dioxide concentrations requires non-marginal reductions in energy consumption (see also Imboden, this volume). To assure global economic welfare this can only be accomplished if energy efficiency is improved and if efficient technologies are adopted by developing and threshold countries.

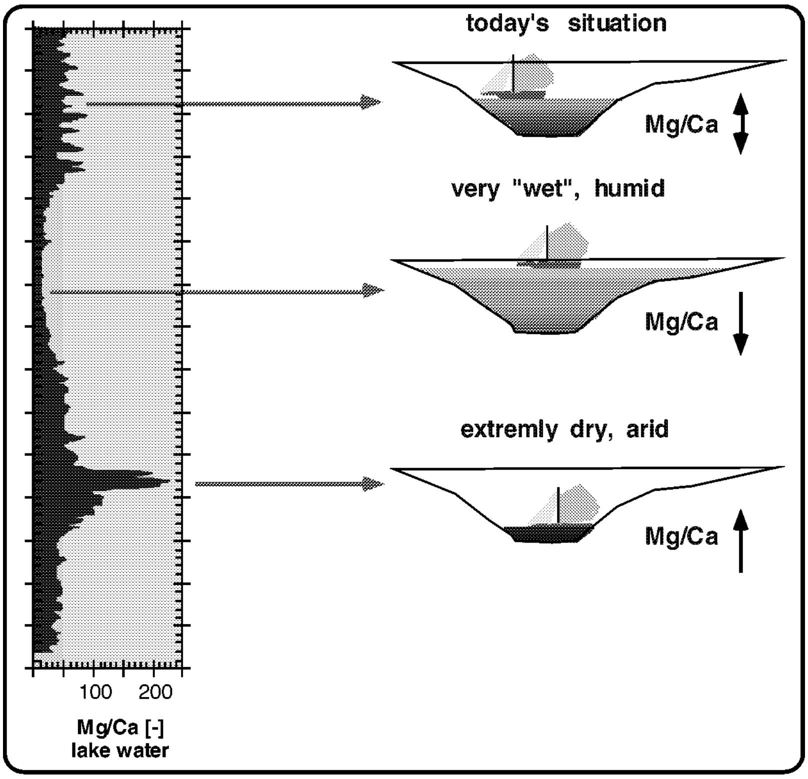


Figure 6. Diagram with paleodata for historical evidence and a visualization for changes in lake levels that reflect major climate changes. The data were derived from Lake Van in Eastern Turkey that constitutes an excellent climate archive due to its laminated sediments.

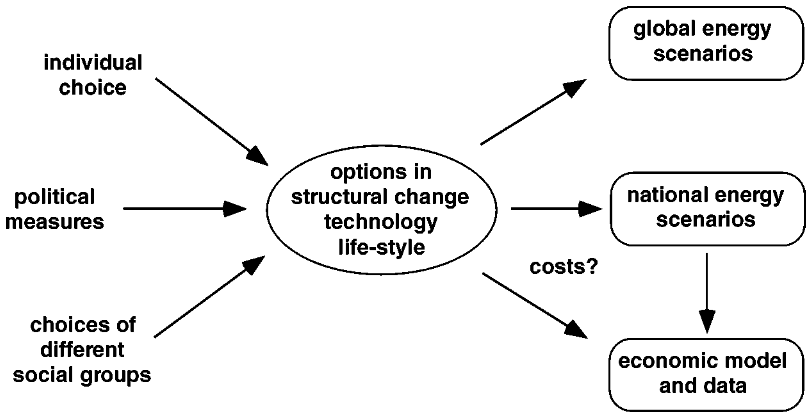


Figure 7. The most important parts of OPTIONS and their relationships.

- The calculator for national energy scenarios allows a comparison of the current state of energy consumption, a trend prognosis (for the year 2030) and a user defined scenario. National energy scenarios can be derived as a function of options for individual lifestyle, technology, economic growth and structural change. Per capita energy E_c consumption is derived as the product of the number of energy services consumed and the energy consumption per service unit:

$$E_c = \frac{\sum_j N_j \mathrm{Int}_j}{P},$$

where N_j is the number of units of energy service j and Int_j is the energy consumption per service unit. Technological improvements lead to a reduction of Int whereas behavioural and structural changes lead to a change in N. The trend scenarios indicate that improvements in energy efficiency are more than compensated by an increase in the number of energy services consumed.

- An economic growth model allows different possibilities for the relationship between economic growth and energy consumption to be explored.
- A catalogue gives an overview of measures at different levels of societal organisation.

OPTIONS introduces the idea of a low energy society to embed the climate change decision problem into a wider range of societal concerns. Such an embedding is particularly important for the consideration of options to mitigate climate change at the regional scale. Regional action to reduce carbon dioxide emissions cannot prevent regional damage from climate change caused by the total of global carbon dioxide emissions. A scenario of a low energy society requires a broader perspective than it might be suggested by simple cost-benefit considerations. In particular, it is argued that one needs to address

- the desirability of a low energy society as an image of a future society;
- the presence of a plausible and desirable path to get there;
- the presence of attractive options for different social groups.

The national energy scenarios in OPTIONS provide evidence that a low energy society is feasible in principle by using the best technologies available and by making appropriate lifestyle choices. The following major sources of uncertainty are crucial for the evaluation of any options in this respect

- the effectiveness of combinations of measures;
- the costs in the short- and the long-term for different social groups.

5.1. Effectiveness of combinations of measures

Figure 8 shows the catalogue of measures that has been included in OPTIONS. The measures are of different kind and cover a wide range of different levels of societal organisation and institutional settings.

Market Instruments
CO_2-tax
Ecological tax reform

Fixed Targets
CO_2-emission certificates
energy ceiling

Governmental Regulations
fixed technological standarts
sunday driving ban

Voluntary Agreements
Commitments of business
global action plan

Supporting Measures
funding of research and
technology information and
education

International Measures
role of Switzerland in policy
process global economy

Figure 8. Overview of the measures catalogue included in OPTIONS.

For each of the measures in the catalogue, OPTIONS provides information about the state of the public discussion, the anticipated effects on energy consumption and economic growth. Uncertainties are highlighted in particular as far as costs and effectiveness are concerned. However, there is a lack of a coherent modelling framework in which the combined effects of such a catalogue of measures at different institutional settings could be addressed responsibly by accounting for major uncertainties. What is for example the combined effect of an energy tax and funding of research and technology? How could an energy ceiling, a fixed target for national energy consumption, be obtained? What is required is the development of scenarios in which subjective probabilities derived from expert judgements can be included. An approach in this direction might comprise agent based modelling and probabilistic scenarios.

In the present version of OPTIONS, users can explore national energy scenarios and compare them to the predicted changes for a trend scenario. The trend scenario indicates that improvements in energy efficiency are expected to be more than compensated by an increase in the consumption of energy services. Figure 9 shows a scenario where all options for improving technological efficiency to the highest level according to current knowledge have been activated. The other options are set to the same values as in the trend scenario. Citizens can use the measures catalogue and judge the different measures based on what they consider feasible and on what they consider desirable in order to achieve a certain target. However, desirability may depend crucially on the costs anticipated for a reduction in energy consumption.

Figure 10(a) gives an overview of different political measures and the corresponding reductions of energy consumption currently discussed in Switzerland. Figure 10(b) shows the anticipated increase in the prizes of gasoline. It is evident that within such a paradigm the transition to a low energy society would be associated with high costs and may thus not be very desirable.

5.2. Costs in the short- and the long-term

To discuss a plausible path towards a low energy society requires an understanding of evolutionary change in socioeconomic systems. In OPTIONS, uncertainties surrounding the relationship between economic growth and energy consumption can be explored with a simple economic growth model [17]. The user has the possibility to explore the implications of different assumptions regarding cost curves. One may consider different scenarios for economic output (GDP) and energy consumption (EC):

Trend: GDP+, EC+

In the trend scenario a continuation of the current trend of modest economic growth with modest improvements in energy efficiency results in a modest increase in energy consumption. This is the most likely development for Switzerland according to economic forecasts (Prognos, 1996).

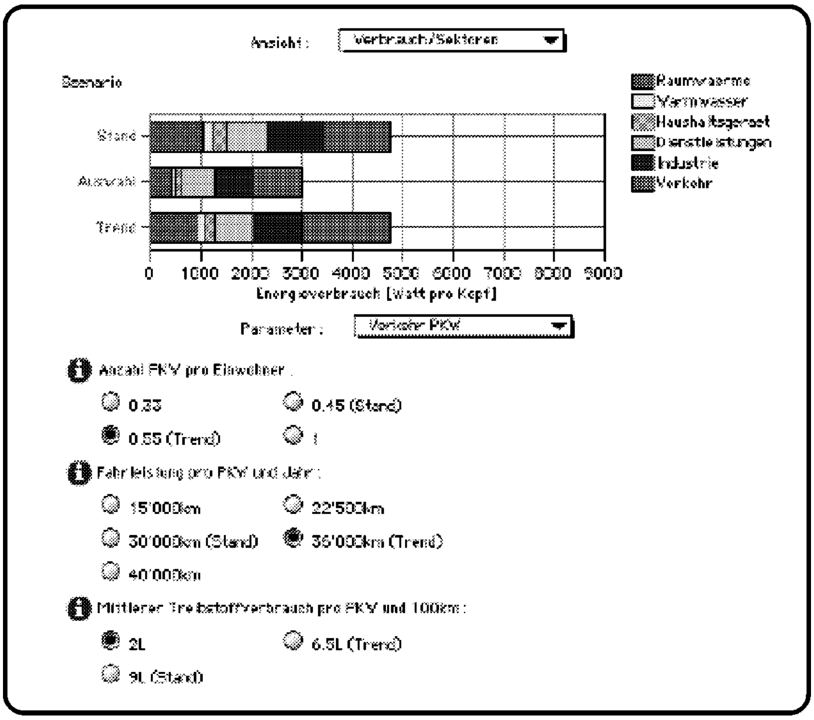
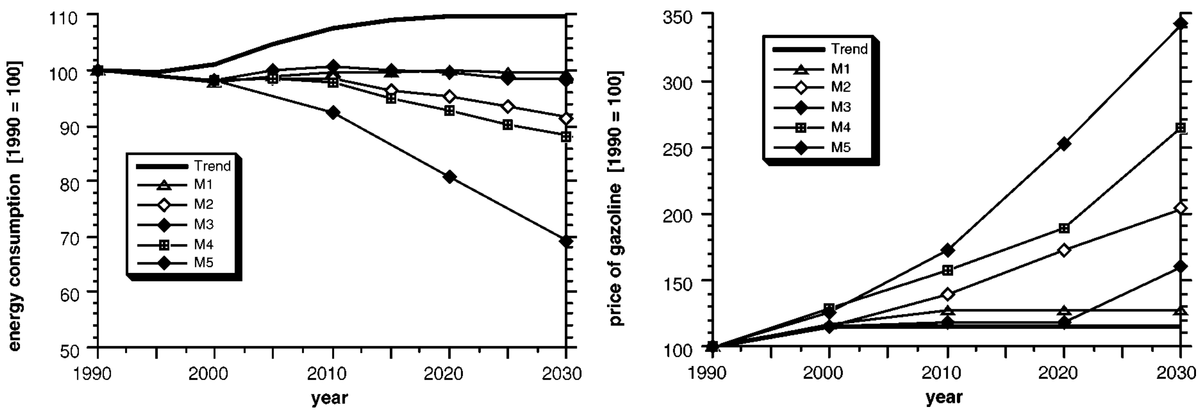


Figure 9. Calculator for energy scenarios that allows the user a comparison of the current state of energy consumption, a trend prognosis (for the year 2030) and a user defined scenario. For the chosen scenario all options for improving technological efficiency to the highest level according to current knowledge have been activated. Other options as in the trend scenario. Energy consumption was derived from the data of the Swiss federal energy statistics. It does not include grey energy, the energy imported indirectly via goods.



(a) (b)

Figure 10. Effects of different political measures on (a) energy consumption and (b) prize of gasoline. The measures refer to: Trend, M1 = CO_2-tax, M2 = energy tax (energy-environmental initiative corresponding to an ecological tax reform), M3 = solar initiative (subsidy for solar energy derived from an energy tax), M4 = combination of M2 and M3, M5 = scenario for increased sustainability with an energy tax not in the public debate.

Crisis: GDP–, EC–

In the reduction and crisis scenario a reduction in energy consumption is accompanied or even triggered by a decline in economic output.

Innovation: GDP+, EC–

In the innovation and qualitative growth scenario a decline in energy consumption is a result of increased energy efficiency. The improvement in efficiency is assumed to be a result of a major surge in technological progress and structural change that lead to an increase in economic output.

Both economic forecasts and citizens' expectations (Jaeger et al. this volume, [18]) provide evidence that a major increase in per capita energy consumption (e.g., from currently 6000 W to US levels of 10 000 W) is not considered a plausible scenario.

Figure 11 shows two scenarios for energy consumption obtained with the economic growth model. The red scenario corresponds to the trend. The green scenario corresponds to an innovation scenario. This change was effected by the introduction of an energy tax at a level of 50% of the energy prices. Tax revenues were redistributed to subsidise inno-

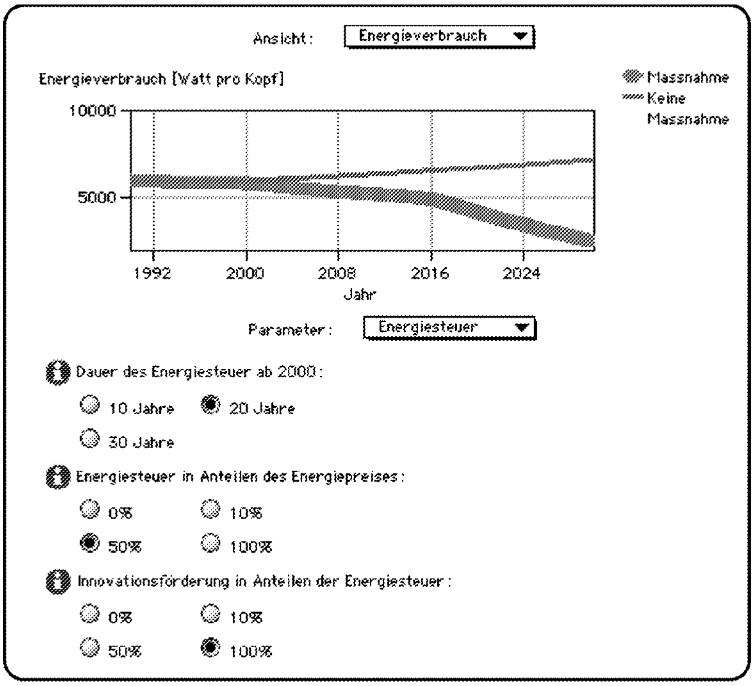


Figure 11. Scenarios for energy consumption derived with a simple model for economic growth in OPTIONS. The user has the possibility to choose among a number of options such as energy tax, targeted investment and effects of imitation. He can also make assumptions regarding the shape of the cost curve. In the chosen scenario the curve corresponds to a shape as curve (2a) in figure 12.

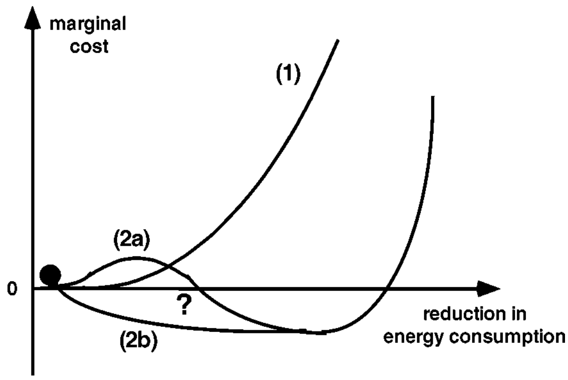


Figure 12. Different possible behaviours of the marginal costs for a reduction in energy consumption. The black circle denotes the current state of an economic system. (1) increasing marginal costs in a one equilibrium world; (2a) cost threshold and evolutionary transition to another development path towards a low energy society; (2b) evolutionary transition towards a low energy society without cost threshold. The question mark indicates that the shape of the cost curve is highly uncertain.

vations. The strong decline in energy consumption results from the fact that a cost threshold is passed. Such assumptions do not correspond to the view of ever increasing costs for increasing reduction in energy consumption (see also figure 10). The model allows the user to explore the effect of different assumptions on the shape of the cost curve.

Figure 12 shows two different shapes for the marginal costs for reducing energy consumption as a function of the reduction in energy consumption already achieved. The costs are assumed to be the total aggregated costs for an economy as a whole. The model emphasises the difference between the view of equilibrium dynamics (1) and the possibility of evolutionary dynamics and a transition to another development path (2) as reflected in assumptions regarding the shape of the cost curve. Increasing costs are derived from "top down" macro-economic and general equilibrium models. The conventional models incorporate strong implicit assumptions about maximisation, technical progress and organisational efficiency that predetermine their results. Such approaches predict that a perfectly competitive market exploits all opportunities for decreasing energy intensity that are profitable at current prices. For any further reductions in energy consumption opportunities will be exploited. Curve (1) in figure 12 represents a typical cost curve with increasing marginal costs derived from such assumptions. In such a case measures for reducing energy consumption can only be justified by external effects which are neglected in the current accounting structure of the economy, e.g., the reduction of environmental damage resulting from an excessive consumption of energy.

Curve (2a) in figure 12 depicts an alternative shape of a cost function in which, after an initial increase, the costs will fall once the cost barrier is crossed. Negative costs imply that improvements in energy efficiency result in a net profit for the economy as a whole. The initial increase of the cost function is derived from the assumption that investments are made into human capital, research and development and structural change. Such investments may not be profitable in the short-term. However, a well-directed investment strategy is assumed to trigger a self-reinforcing process of radical innovation and evolutionary socio-economic change. Radical implies that such a shift towards a low energy society embraces innovations in lifestyle, technology, infrastructure and institutional change. Curve (2b) indicates that there might be even a path where an appropriate investment strategy leads to an immediate reduction in costs. Such cost assumptions are mainly derived from technology data [19]. Obviously a major issue of uncertainty remains needs to be clarified.

Due to lack in effects, market forces alone would not move the current state of the system towards a low energy development path. A similar argument was made in quite another context with the so called "poverty trap" [20]. One can think of a poverty trap as a stable steady state with low levels of per capita output and capital stock. This outcome is a trap because, if agents attempt to break out of it, the economy tends to return to the low-level steady state. Similarly, one may talk here of a "high energy trap".

Being in a "high energy trap" agents cannot easily break out of a state with low energy efficiency. An escape must proceed within a process of collective decision-making. In this highly aggregated conceptual model the marginal costs for improvements of energy efficiency cover a wide range of processes. They represent an aggregate of all direct and indirect effects which are associated with this change. It is therefore difficult to make statements regarding the overall shape of such a cost curve. Decreasing marginal costs as a function of market share are well documented for single technologies (e.g. [21]). They can be explained by effects of increasing returns to scale. Such effects will be important in fostering a transition to a low energy society. Another argument for the presence of such a cost threshold is the assumption that the economic system as a whole does not operate at its production possibility frontier. The trade-off between economic growth and reductions in energy consumption is derived from the assumption that the current system uses its inputs in the optimal fashion to produce economic goods. Numerous studies show that firms and organisations do not operate at maximum efficiency [19]. In such a case it is plausible that technological and structural change may reduce energy consumption and increase economic efficiency at the same time. In particular, it is difficult to derive estimates for the efficiency of using human capital. This efficiency may in general be overestimated. The argument made here goes one step further in stating that efforts to improve the efficiency in energy consumption trigger structural and technological progress and mobilise a creative potential of the economy as a whole that currently remains idle. To support such an argument implies additional research to explore the potential relationship between improvements in energy efficiency and improvements in the structural and technological efficiency of the economy as a whole.

Aggregated cost curves for the economy as a whole are not very meaningful if it comes to decision-making. It is difficult but vital to account for costs and benefits for different social groups in the short- and the long-term. The current debate on costs is still dominated by the type of argumentation based on the shape of a cost curve such as curve (1) in figure 12. Figure 10 gives a vivid example for that. It is argued here that costs will be highly path dependent and thus difficult to predict. What is required are strategies for robust action by which short-term options are explored by maintaining long-term degrees of freedom.

6. Conclusions

Within the CLEAR project a new approach was developed to produce models for participatory integrated assessment. Integration is not performed in one integrated model but in the participatory process. The computer serves not only as a means for calculation but also for communication in terms of transfer and dialogue. Models are implemented within a context of different types of information. Information of high scientific quality is produced in a form accessible for the general public. To improve the usefulness of models for the decision process, integrated assessment modelling should be embedded in a participatory process in which stakeholders are involved. Validation of traditional IA models against real world data is a difficult endeavour. Models developed for a participatory integrated assessment should primarily be validated against how they structure the debate about a problem. In this respect, they follow more the tradition of soft systems analysis (e.g. [22]). Methodological investigations are required to improve the validation process.

Our experience in citizen focus groups shows that scientific uncertainties are very difficult to communicate. They may not be perceived as a trigger but as an impediment for action. The origin and the importance of irreducible uncertainties cannot be easily conveyed to the public. Accounting for uncertainties is not in agreement with the view still prevalent in the public of scientific experts speaking "truth to power". Besides, when the models were applied in educational settings (high schools, universities) dealing with the topic of uncertainties posed difficulties as well (Büssenschütt and Pahl-Wostl, in prep). The problem is not only located at the level of communication but also in how science itself deals with uncertainties in the research process and in universitary education. Despite the numerous attempts for making typologies for uncertainty classification (review in [14]) the current scientific practice and public perception are still unsatisfactory.

An improved understanding of uncertainties is crucial for discussing options for mitigating climate change. To combat climate change will require major reductions in energy consumption and consequently major changes in today's socio-economic systems. Such changes cannot be brought about by conventional policy measures. We advocate a new approach of a polycentric understanding of policy that invokes instances of social learning at different levels of societal organisation. An important research question is the development of concepts and models of institutional change that focus on the mutual relationship between processes of social and individual learning, between macro- and micro-level, between individuality and the embededness in social networks. Models that may be particularly suited for this type of research are models between knowledge management and

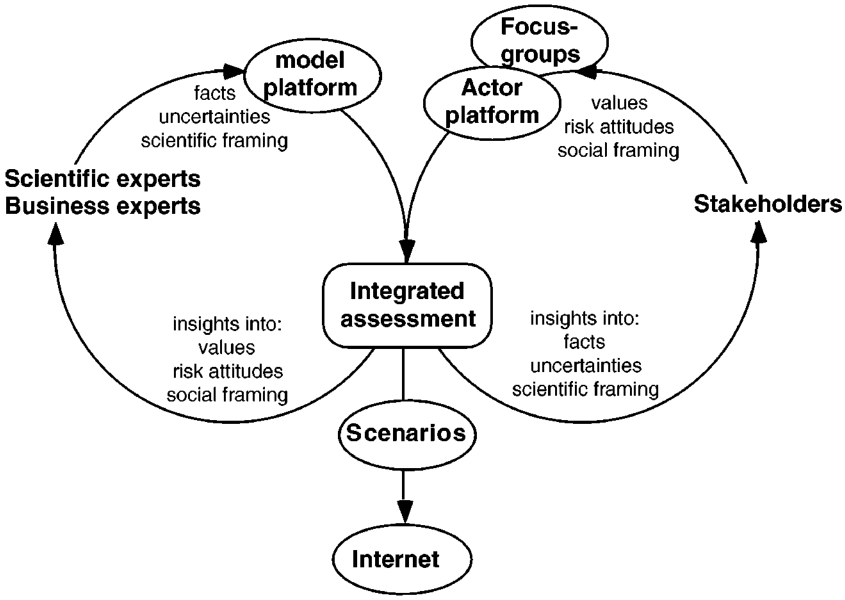


Figure 13. In an extended process of social learning the model platform may comprise different components, e.g., ICITs and agent-based models. The participatory process may include citizen focus groups, on one hand, and actor platforms with representatives from different social groups, on the other hand.

simulation of real world actors. This is a typical field for the application of artificial intelligence and agent based modelling. Whereas traditional AI was mainly targeted at developing expert systems by methods of knowledge engineering, distributed artificial intelligence is targeted at making use of this knowledge in a dynamic fashion and simulate the processes of decision-making. Evolutionary approaches allow learning behaviour and social change to be modelled. Agent-based modelling may thus be viewed as a promising approach to developing models for participatory settings.

A polycentric approach to integrated assessment means that the policy process encompasses several scales in space and time and has consequently to include a wide range of different measures and institutional settings. The policy process regarding climate change was primarily centred at the global scale – UNFCC and RIO process. IPCC alike is targeted to inform this global policy process. However, the need for regional approaches soon became evident because national interests impeded any global treaties and short-term expectations determined decision-making at the regional scale. A polycentric policy process implies that decision-making at the national scale depends on expectations of the global process, e.g., first mover advantage in developing energy saving technologies if one expects a global agreement to reduce energy consumption. Decision-making at the global scale is guided by the decision-makers' perception of possible consequences at the national and regional scale. Overall, the decision process may be viewed as the mutual shaping of expectations at different scales from the individual citizen to the global policy process. It is argued that agent based models that allow the behaviour of real world actors and the development of expectations in a realistic fashion to be represented were particularly suited to represent and foster processes of social learning among different stakeholder groups and across scales. Figure 13 shows such a setting in which the model platform may comprise different components, for example ICITs and agent-based models. The participatory process may include citizen focus groups and actor platforms with stakeholders and representatives from different social groups. Currently such an approach is adopted in a project on water resource management. A responsible integrated assessment has to portray the full range of possible future trajectories. Agent-based models allow the uncertainties inherent in the dynamics of socio-economic systems to be expressed; uncertainties that are crucial to explore unconventional future scenarios as for example the idea of a low energy society. Uncertainties may thus not only be perceived as a threat but also as an opportunity.

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