



Sustainability Science



## Integrating Science for Sustainability

The 21st century will either witness the transition to global sustainability or the further separation of cultures and generations into winners and losers under accumulating environmental and developmental pressures.

Sustainability science is an emerging discipline of science dealing with the question of how our societies can be transformed in order to bring about a sustainability transition. This sustainability transition will change our social, political, and economic institutions and procedures in a way that is beneficial for both human societies and the ecological systems they are part of. Examples are the transformation of the energy system from being carbon based to a non-carbon solution; an approach for

how a growing world population can use its nutrition base without degrading it; or a world water management which makes sure that clean drinking water is available all over the world. Research on the sustainability transition involves various scientific disciplines from the natural and social sciences, because a profound and practical scientific understanding is required of the myriad of processes and interconnections that make up our living Earth - be it the formation of sea ice, the breathing of forests or the use of land and water resources by human society. Studying parts in isolation will not suffice: an integrated science of the Earth system is called for.

## Coevolution of Nature, Society and Science - The Dynamics of a Complex Relationship Becomes Critical

By John Schellnhuber

The term "sustainable development" has become a fashionable expression in the vocabulary of the modern cosmopolitan. It indicates a *balanced interaction of ecological, economic and social concerns*, and does so in a conveniently vague way. The literal German translation as "Nachhaltige Entwicklung" goes even one step further, offering an almost vacuous concept whose content can be (mis)construed to suit the aims of almost any interest group - especially in the context of contemporary politics. The German Bundestag recently established a "Sustainability Council" comprising influential representatives from all societal segments and strata, who discuss and, if necessary, negotiate the integration of socio-economic and ecological development. The intention is entirely praiseworthy, and the Council may indeed prove constructive - if its members succeed in setting aside their own particular interests and address the heart of the matter without further delay.

But what exactly is the "heart of the matter"? Countless more or less scientific publications have addressed the subject of sustainable development since it was catapulted into the discursive arena by the Brundtland Commission in the 1980s. Unfortunately, most of these discussions have failed to arrive at an acceptable definition which goes beyond the well-meaning but simplistic notion of "satisfying basic human needs without destroying the Earth!". Thus, a few years ago, I set out to unearth the logical core of the concept of sustainability. My efforts have led me to the conclusion that this core is

divided into distinct chambers that house fundamentally different interpretations: The rigorous adherence to minimum ecological and socio-economic standards; the perpetual maximization of global social welfare; the containment of potentially disastrous risks; the establishment of the equity principle in an everlasting intergenerational contract; and the implementation of an acceptable state of planetary equilibrium, which would mark the end of all environmental history - each of these paradigms (individually or combined) could be made the objective of sustainable development [1].

The general discussion on "sustainability" has recently been refuelled, gaining considerable depth of focus. This was evident at the Global Change Open Science Conference in July 2001, which brought together in Amsterdam more than 1800 environment & development researchers from 100 countries at what can be considered the scientific counterpart to the political Earth Summit in Rio de Janeiro in 1992. In a plenary session at the conference initiated by Bill Clark (Harvard University, USA), the birth of a new science, christened "sustainability science", was announced. In his subsequent characterization of the fledgling discipline, Clark drew heavily on the seminal essay that appeared in the American Science magazine in April 2001 and was written by an interdisciplinary team of authors (including two PIK researchers) [2]. In view of the introductory remarks about semantic vagueness, I will employ my authorial privilege and henceforth interpret the term sustainability science as

"coevolution science". This also provides an adequate translation into German, namely "Koevolutionswissenschaft".

For in fact, the envisaged new science involves a vast complex of factors, namely the closely linked and reciprocally accelerating evolutions of nature, society and knowledge on a global scale - a process, which must not only be concisely explained by the scientific system, but in which this system has to reinvent itself. Thus, *nota bene*, coevolution science is both the objective science of human-environment coevolution and a subjective coevolving factor of that dynamic interaction. These statements require further explanation. I would like to offer one by relating the true story of a fictitious microcosm.

### The Parable of La Trinidad

On the rocky plateau of the most remote south-eastern flank of the Pyrenees, high above the Noguera River, perches the mountain village of *La Trinidad*. When water flows in this river at all, it radiates a beguiling forget-me-not blue only encountered in the high-lying regions of Aragón or Catalonia. Over the course of the centuries, the grey slate houses of the village have slowly crept up to the precipice of the cliffs, becoming an organic extension of their steep wall. Since time immemorial, the village's inhabitants have supported themselves through local agriculture and simple handicrafts: Cultivating wine, fruit and olives in the tillable soils of the slopes above the village, carving household tools from the wood of the box tree, weaving leather shoes or producing other such crafts. A simple and monotonous, in other words, controllable and predictable existence. But life in La Trinidad is threatening to be thrown out of balance.

More and more members of the community complain of cracks and fractures in their buildings, stone avalanches have frequently swept goats and sheep over the precipice, and a crevice - wider than the hand of a child and with no recognizable bottom - has materialized through the centre of the Plaza Mayor. Most inhabitants are bewildered, some frightened and a few already prophesy the demise of the village, whose ruins will plunge into the Noguera far below, shoring up its waters to form a massive lake.

The leaders of La Trinidad are called upon to take action. The mayor convenes a special assembly of the community council, which after long debate decline to reach any concrete conclusions or undertake measures

without first getting a problem analysis from a "top-notch expert commission". Its members are quickly found: The head of the local school; a geologist from Zaragoza, who with his own laborious efforts converted a half-deteriorated stable into a comfortable holiday home in the village; and, finally, the prior of the nearby abbey, Nuestra Señora de los Ángeles, who is widely reputed for his architectural knowledge. The experts take ample time to conduct on-site investigations of the troubling changes, to search for potentially similar developments in neighbouring villages, to go through the libraries of the province's capital for relevant information, and to lead a number of heated debates. After five months, they present the results of their investigation in another special assembly of the community council: Everything points to the conclusion that massive tensions are building up within La Trinidad's host mountain, which are manifesting themselves in distinct but, as yet, still moderate structural damage. Potential causes include natural, as well as external factors, perhaps even human influence. Causal relationships can only be established through an extensive and costly measuring process over a minimum of two to three decades. An immediate collapse of the entire plateau is unlikely, but cannot be completely ruled out...

The report serves to exacerbate the confusion: Must we, can we, should we do anything given the slim body of evidence? Several council members argue that, for the time being, the findings should not be released, but after intense debate it is agreed that the council must unconditionally fulfil its duty to inform the community. This could only happen by quickly organizing a citizens' meeting. The following Saturday evening, village locals stream onto the Plaza Mayor - gathering, indeed, on the putatively safer slope of the damaged area. The mayor briefly portrays the seriousness of the situation and calls the public to discuss the crisis with the words: "The future of La Trinidad is in your hands!" The discussion slowly gathers momentum although nobody yet realizes that this evening marks the turning point in the village's fate.

A flood of conjectures - banal, astute, ridiculous - circulate among the villagers: Too many new buildings have been constructed in the last few years, whose weight can no longer be supported by the rock. The heavy all-terrain vehicles used intermittently by tourists, but also the tractors employed of late by several farmers, bring the ground into dangerous vibration. No, cry others, fault lies alone with the provincial government and its foolish development projects funded by the European Commission. Who could still doubt that blasting the gigantic new

tunnel to France through the neighbouring mountain range has compromised the structural integrity of the entire region? Other citizens, whose spokesman has studied geo-ecology in Madrid for years but regularly returns to La Trinidad for the semester breaks, contend that the actual cause is to be found in human-driven environmental changes. Have we not let the terraces behind the village, which generation after generation has built into the slopes to fight ground erosion, visibly deteriorate? And what of the heavy harvesting machines that compress the soil of the fields to impenetrable cement? Is the groundwater level not sinking due to the numerous wells dug to enable the transition from traditional agriculture to quasi-industrial production as encouraged by the new national support guidelines? Corn instead of millet, apricot trees instead of olive groves, dessert grapes instead of age-old wine varieties, such as Garnacha and Cariñena: The thirst of these "cash crops" has proven to be nearly insatiable. And worst of all the attempts to reforest the barren Sierra on both sides of the village with Eucalyptus trees. A tiny but unyielding minority of the congregation is of an entirely different opinion: Not human beings but the moon determines the fate of La Trinidad! Decades of observations gathered by a sheep herder with a flare for the natural sciences have clearly shown that the cliffs work in precise rhythm with the phases of the Earth's companion.

At some point the focus of the discussion turns from determining the causes of the phenomenon to the practical consequences for the lives of the villagers: Indeed, we may know precious little, but we know enough to take action. The most urgent goal must be to stabilize the structural foundation of the ensemble, possibly by permanently sealing the largest cracks in the natural rock; only if these measures prove unequivocally futile would an evacuation plan be drawn up as an *ultima ratio*. These apparently entirely rational suggestions raise strong objections from the more spiritual members of the group: The superior force of nature can hardly be stopped in its tracks by such stop gap measures. The

modest financial reserves of the community should be used instead to organize a monumental candle procession - after all, this had already proven successful against the great drought of 1786. But the wait-and-see position also has its say: Who acts over hastily now will in all certainty proceed incorrectly and waste the savings of the community, which are desperately needed to satisfy immediate needs, such as the construction of the long-desired public swimming pool. Not to mention that there have always been cracks in the walls of the houses and the grandchildren of today's inhabitants will most likely leave the village for the city anyway.



It is long past midnight by the time the chorus of arguments and counter-arguments begins to subside. The village leaders briefly withdraw to confer; then they present their summation and an astounding proposal: Evidently, a solution for the enigma of La Trinidad remains to be found, however, the day's discussions have brought forth many valuable suggestions. It would seem that there is no simple overarching explanation due to the apparent interrelation of a number of factors not recorded in any available textbook. Nevertheless, the community could not wait for new literature to appear - conceivably, the fate of the village was already hanging in the balance. If the current

obdurate dealing with nature continues, the scales could tip catastrophically. The situation called for an immediate change of attitude to make decisions which none of their forefathers had ever faced. They could attempt to defend the entire village with every means at their disposal in a bid to conquer the nameless, menacing adversary. Of course, they might also decide to relinquish the most unstable parts of the village, salvaging what they could and in certain cases must. First and foremost, the early 12th century Santa Bàrbara church with its unique Romanesque fresco. The virtually dilapidated pauper dwellings at the precipice, on the other hand, hardly seemed worth investing any major effort. Ultimately, the villagers might have to come to terms with the regrettable fact that La Trinidad would eventually have to be completely abandoned. The villagers could only survive this exodus, however, with substantial support from the

state government, whose promises could not be trusted without reservation. Indeed, the authorities would gladly lend a helping hand to rescue the church fresco, in the interest of placing it in the world-famous museum on the Montjuic in Barcelona.

The local council, however, did not consider itself in the position to take responsibility for decisions of such enormity. This critical situation required the total mobilization of joint resources and a new formulation of political demands and objectives. Therefore, they would immediately establish a "welfare committee", comprising the relevant social forces, to which all individual observations of and speculations about pertinent developments should be reported and which would continuously process this information. The committee was expressly authorized to prepare priority lists for the preservation or relocation of valuables and to carry out a preliminary economic assessment of these objects - for the purpose of insurance claims and compensatory payments. From now on, the community meeting was to take place on this square quarter-yearly to discuss the welfare committee's report and to update both its mandate and its configuration. This process was designed to forge a new identity for the village community that would either unite to find a solution to the crisis, or perish together in full awareness...

### **Global Coevolution**

The parable of La Trinidad lends contour and substance to the dynamical interactions between society, nature and science as stylized in the introduction. In the imagined (yet by no means imaginary) scene, far-reaching changes in socio-economic structures trigger an inexorable chain of events. The interaction of these human factors - coupled, perhaps, with the unpredictable processes of nature - rapidly transform the familiar environment and, in turn, alter the community through numerous hitherto unknown burdens and risks. Since existing policies of crisis management are no longer effective - in part because the inherited cognitive system cannot provide adequate or timely problem-solving knowledge - the social body (along with all its organs for knowledge production and the adoption of political objectives) must continuously re-design itself in tune with the "unbridled" forces of nature. The village's very survival may depend on this.

Today, an analogous process of rapid, open coevolution has seized the planetary system as a whole and taken on a unique dimension in history. The aforementioned

Amsterdam conference has corroborated this view with an impressive array of insights and data accumulated over the past fifteen years [3]. The central message of the conference summary maintains that, since the onset of the industrial revolution, the Earth System has been forced to deviate from its natural modes of operation through the manifold influences of civilizations around the globe. Human-driven changes - such as variations in the physiochemical composition of the atmosphere, alterations of the continental surfaces brought about by agriculture, and the perturbation of global water and sediment balances - produce multiple interrelated environmental effects which cascade through the planetary machinery in complex ways. Because the operation of this machinery is to a large extent nonlinear (with disproportionate reactions to all kinds of intervention), it is not unimaginable that our civilization could inadvertently activate "ecological switches", triggering abrupt changes in regional or even global environmental conditions. Frequently cited examples of such "critical phenomena" include the suppression of warm ocean currents through the shift of large-scale precipitation patterns in response to anthropogenic climate change as well as the reorganization of the Asian monsoon system as a result of changing meteorological properties of the region's terrain due to expanding agricultural activity, excessive deforestation, and accelerated colonization. Moreover, it is virtually impossible to quantify the probability - let alone the timing - of such events with our current state of knowledge. Humanity must therefore live with environmental risks which can be categorized somewhere between Don Quixote's windmills and Damocles' sword. This lends particular charm to the "Anthropocene", as Nobel Prize winner Paul J. Crutzen refers to our current geological epoch.

The profundity of the problems involved and the scope of the potential consequences represent an unprecedented challenge not only for international politics, but also for our scientific community as a whole. In this context, the classic paradigm of "optimal control" - where we freely choose objectives for the system at stake and implement them down to the last detail with the help of precise expert knowledge pre-collected to cope with any eventuality - becomes a chimera. For instance, it is absolutely impossible to accurately predict the impacts of, let's say, a ten-fold increase in the CO<sub>2</sub> content of the atmosphere - and who would be prepared to undertake such an experiment in the interests of ascertaining the truth? But even the identification of appropriate objectives - for economic growth, improved quality of life, environmental integrity - has become a task that no one



is really willing to tackle, not even the most legitimate and best-fed think tanks of the world. This observation reveals an element of dubiousity in the entire sustainability debate: anticipating the needs of future generations means to *construct* those needs, and thereby guide the development of the planet in such a way that our descendants will have no choice but to accept the demands that we, in the truest sense of the word, have provided for them! More serious, however, is the fact that research can say virtually nothing about the needs of the vast majority of *present-day* generations, since these people happen to have been born far from the citadels of Western welfare [4]. The landmarks of progress fade into the fog...

### Facets of Coevolution Science

The Amsterdam Declaration attempts to address the problematic sketched above by fostering the development of a concerted *global system* for environmental sciences in the broadest sense. This system is to distinguish itself through innovative integration methods, transnational structures and perpetual dialogue with affected individuals and interest groups throughout the world. Such aspirations bundle and "earth" a powerful contemporary discourse which is dedicated to the project of "reinventing science" in an age of proliferating uncertainty [5]. Protagonists of this debate stress that today's scientific knowledge is produced within the rapidly thickening *context* of its social effectiveness. Furthermore, they argue, this context is not quietly absorbed by the scientific system, digesting and ruminating the cognitive progress, but speaks back to the system at full volume via a thousand-and-one channels. This is not something to be feared - on the contrary, it should be seen as an opportunity to establish a good partnership between society and science based on dialogue and mutual respect.

Within the emerging conception of coevolution science, all these facets are assembled and allocated through a

"grand unification" of nature, civilization, cognition and their interrelationship. This is a vitally necessary step, as the three respective bilateral relationships in this *ménage à trois* have meanwhile reached critical intensities. Yet coevolution science is not just contemplating (and possibly explaining) the total Earth System, but also represents the potential balance spring of this machinery. For example, it constructs scenarios of technological progress and anticipates its impact on the environment and society, whereby this very progress may be either fostered, rejected, or modified in the first place.

Coevolution science will distinguish itself in essential ways from the "classical" Popperian fairytale world: It will frequently be strategic, not contemplative; qualitative, not exact; hypothetical, not falsifiable; preliminary, not categorical; contextual, not universal; participatory, not objective. And nevertheless, it will seek to establish the highest degree of clarity, creativity and precision. However, our object of study is no longer a single, eternal electron immersed in a perfect, infinite magnetic field. Instead, we must examine complex ecological systems whose individual determinants are impossible to sort out, so that we are forced to employ sophisticated methods for causal pattern recognition. We must study dynamics that are either too slow to be perceived by automated monitoring systems, or too erratic to be predicted using conventional

approaches. The virtual reality of computer simulations will at least allow us to access fuzzy caricatures of those processes. We must study the most vulnerable elements of the general nature-humanity relationship, since a comprehensive exploration of the causal matrix involved lies beyond all analytical capability. Inverse approaches, which depart from those elements to construct their multidimensional perturbation potentials, may prove to be the appropriate cognitive tools in this context. Finally, we must study the totality of limited-rational actors, whose environmental and developmental behaviour is at best governed by weak statistical laws. Coevolution sci-



The Pantocrator (Christ represented as the ruler of the universe). Romanesque church fresco from Sant Climent de Taüll (Vall de Boí, Pyrenees, Spain).

ence will not hesitate to stage the self-modelling of those actors in digital "decision theatres" and to thereby realize the *coproduction* of knowledge in its true sense.

Even this brief illumination of but a few facets of the new science should make evident that giant creative wheels of wisdom must be set in motion. This will require many strong and indefatigable shoulders pushing ahead in unison. In this light, the aspirations outlined in the German government's Sustainability Strategy in December 2001 appear rather weak and unimaginative: By means of a shopping list approach of "twenty-one indicators for the twenty-first century" [6], we are to find our bearings on the road towards a long-term pact among nature, industry and civil society. In the process, however, the strategy is mistaken for its operationalization, and ritual hearings of notorious interest groups are confused with the genuine coproduction of sustainable insight. This is all the more regrettable as the conditions necessary to provide such insight rapidly unfold around us. As long as volition and wisdom (or, in old-fashioned terms, might and mind) fail to unite in an intensive, dynamic and respectful partnership, however, many a temptingly obvious strategy will lead us astray in the long run.

### Tidings from the Pyrenees

It has just been announced that a quarter of La Trinidad has plunged into the Noguera river below. There are few casualties, however, as the inhabitants of the affected area had already evacuated their homes. This bit of good fortune is attributable to the work of the welfare committee, which had come to the conclusion that the destabilization of the village was due to the dehydration of aquiferous sediments in the host mountain brought about, in turn, by land use changes and, perhaps, other factors. In recent years, the once firm layer of "cushioning" had begun to give way, triggering a geological chain reaction. Through the most intensive co-operation with the local population, the committee was fortunately able to roughly identify the main disturbances in the water storage system, as well as the location of the most critical tension spots. Now the local community intends to focus all efforts on defending the remaining village torso through a number of measures. A series of practices

considered potentially dangerous have been temporarily forbidden. Yet the people will have to dance on the razor's edge of speculation for a considerable period of time ahead. It is nevertheless surprising that the majority of inhabitants are resolute in their decision to stay and help prevent their village from sharing the same fate as countless other ghost towns in the Spanish Pyrenees: La Trinidad will endure for the very reason that it must continually fight for survival ...

### Literature

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The First Sustainability Days



## The First Sustainability Days and the 10th Anniversary of PIK

In October 2001, PIK celebrated its 10th anniversary. It received precious gifts: on October 4th, the totally renovated astrophysical observatory was inaugurated as PIK's new main building. In its basement, this building hosts a new IBM SP high performance computer which was symbolically put into operation on that day. These gifts were given by the State of Brandenburg, the Federal Republic of Germany, and the European Union.

But PIK in turn made a gift to its community by celebrating its jubilee of ten years of innovative research with another scientific invention: the First Sustainability Days. These First Sustainability Days (from 28 September to 5 October 2001) were a pilot series of symposia on sustainability science opening up an annual sequence of similar events, the Second Sustainability Days having already been held at Columbia University, New York, in 2002. The Third Sustainability Days are planned to take place at the University of East Anglia, Norwich.

The Sustainability Days were opened by the Prime Minister of Brandenburg, Dr. Manfred Stolpe, and the Mayor of Potsdam, Jann Jakobs. The Prime Minister highlighted the important contribution made by PIK in shaping the overall concept of "Sustainability". In 1996, the State of Brandenburg joined the "Charter of Valencia" of European regions supporting sustainable development. As a symbolic act the Prime Minister planted an oak in front of the new building.

At the opening event, Professor William C. Clark gave a lecture transmitted live from Harvard University. He discussed the role of the Sustainability Days for establishing sustainability science. Clark addressed three main questions: he asked how global change alters the role of science and technology; what additional knowledge and know-how is needed to promote a sustainability transition; and how to design research systems capable of

achieving this knowledge and know-how. In science and technology, a comprehensive approach is needed to overcome the present division of disciplines dealing with sustainability questions and to integrate the diverse levels and actors in civil society. Examples of pressing practical needs are the world-wide urbanization process, declining trends in African agriculture, and the fight against syndromes of mutual degradation of human and natural systems. In order to tackle these problems, it is important to overcome the present situation characterized by the predominance of single scientific disciplines and a research process that is either problem driven or fundamental and not directly linked to decision processes. Instead, there should be truly interdisciplinary research and a steady stakeholder dialogue. Expertise and applications are to be linked across scales, and the research process should be integrated with decision procedures (see ECF-workshop on page 86). Regional centres are needed to organize local stakeholder processes and to channel knowledge and expertise to solve urgent problems on the local level.

The festive inauguration of the main building marked the social highlight of the Sustainability Days. Erwin Staudt, Director of IBM Germany, one of PIK's sponsors, Dr. Michael Schreyer, EU Commissioner for Finance, Professor Johanna Wanka, Minister of Science and Research of Brandenburg and Professor Schellnhuber, Director of PIK, symbolically set the new high performance computer into operation.

In their addresses, our donors pointed out their reasons for spending a total of 18 million DM on PIK. Dr. Schreyer made clear that climatic change is a key issue in European policy. PIK is a "good customer", she said, in the shop of European research funding, which was all the more remarkable as PIK was celebrating just its tenth anniversary. Professor Johanna Wanka and Wolf-



Michael Catenhusen, Parliamentary Secretary of State, Federal Ministry for Education and Research, both pointed out the important role of PIK in the scientific landscape of the state of Brandenburg and of Germany as a whole. Professor Hans-Olaf Henkel, President of the Leibniz-Gemeinschaft, confirmed his image as a nonconformist by bringing a highly political spirit into the inauguration event. He argued that sustainability should be a universal concept for the survival of our society and should comprise environmental as well as political and economic aspects. Concerning economic and political aspects, he argued against the German eco-tax and cast doubt on the potential benefits Germany might derive from a pioneer role in environmental policy. He judged both these strategies to be unsustainable in economic terms.

Matthias Platzeck, First Mayor of Potsdam and at the time Chair of the German Federal Council for Sustainable Development, took the opportunity to oppose these theses by arguing that the pioneering role of Germany can induce competitive advantages and thus be beneficial both for environment and economy. They would indeed thus be sustainable in the definition of Professor Henkel himself.

After this policy debate, Nobel Prize Laureate Professor Paul Crutzen made his contribution to the inauguration. In 1995 he won the Nobel Prize for Chemistry for his research in atmospheric chemistry concerning the chemical processes causing the ozone hole. He emphasized the crucial role of the climatic stability of the Holocene for the take-off of human culture. With the large-scale emission of greenhouse gases, humankind gave rise to a new geological epoch he calls the "Anthropocene", where human actions have a considerable and possibly fatal impact on natural systems. He was optimistic, however, that this crucial problem could be tackled. He pointed out that in the 1960s the photo-chemical processes of ozone destruction were not known. It was the outcome of theoretical research which, once compre-

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hended, paved the way for effective policy measures that eventually resulted in the Montreal Protocol and the ban of fluorochlorocarbons all over the world. For him, this is a blueprint for climate impact research. The more the impact and mechanisms of climatic change are understood, the more the pressure towards taking political measures will increase.

With this encouraging statement in mind, the audience moved to our new main building where Friedrich Karl Borck, the architect responsible for the renovation, gave a short tour through the building. If you could not take part, see his article on page 90 or have a glimpse at the workshops results.

The gifts being unwrapped, the scientists of PIK were eager to take hold of them. As a first step, a big housewarming party took place on the evening of the inauguration day. Excellent food and wine, swinging tunes from a marvellous trio, a Wilhelminian jewel of architecture and the good mood of the PIK team were perfect ingredients for an outstanding evening of out-of-the-ordinary academic life.





## Scientific Symposia on the First Sustainability Days

To sketch the scientific space sustainability science spans, the Sustainability Days comprised symposia focusing on diverse topics.

The symposium "Methods and Models of Vulnerability Research, Analysis and Assessment" dealt with vulnerability questions and worked towards a definition of vulnerability upon which a research agenda can be built. Vulnerability can be understood as the degree to which an ecosystem service is sensitive to global change in combination with the degree to which a society - or parts of a society that rely on this service - is unable to cope with changes in the quality or quantity of the service (see below). In the symposium "Enhancing the Capacity of Developing Countries to Adapt to Climate Change" 45 experts from developing and industrialized countries, NGOs and multilateral and bilateral donor organizations set up a research agenda to investigate how developing countries could enhance their adaptive potential to hazardous changes of their environment. These hazardous changes comprise both local impacts resulting from climate change and other global change issues. The symposium "Palaeoperspectives on Global Sustainability" took a historic point of view on climate dynamics. Understanding past cyclic variations in temperature and greenhouse gas concentrations is a crucial step for our ability to predict the consequences of large-scale perturbations of the climate system. "Alliances for the Sustainability Transition: The European Climate Forum" was the opening event of this Forum. It was a platform for bringing together stakeholders and scientists in order to jointly define and conduct research related to climate change. The symposium "Contributions to Sustainability Science from Applied Mathematics and Software Engineering" dealt with the specific modelling problems sustainability science poses. Various methods of software engineering, soft computing and numerical mathematics, and their potential to tackle various modelling problems were discussed.

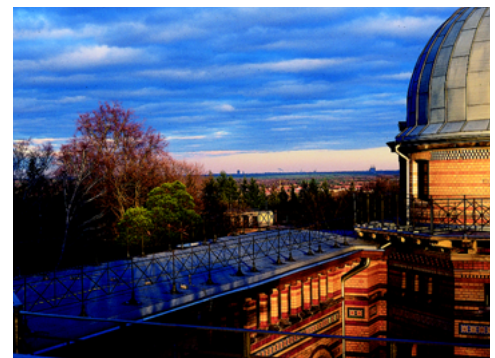
### **Vulnerability: Methods and Models of Vulnerability Research, Analysis and Assessment**

Organizers: Wolfgang Cramer, John Schellnhuber, Bob Corell (Harvard University, USA).

The Vulnerability Workshop was the first part of the "Potsdam Sustainability Days", an annual event that started in Potsdam in 2001 and which it is hoped will wander across the globe in the years to come, promoting sustainability science.

The concept of vulnerability recently emerged from sustainability science as society became aware of global environmental risks such as climate change. Vulnerability assessment turns its attention to changes in the interaction between nature and society, in addition to dealing with the anatomy of environmental changes themselves. The question is "What is the cause of observable changes in the human environment", rather than "What might be likely consequences of drivers of global change". However, a powerful formal methodology to assess environmental vulnerability is still lacking and current approaches use conflicting conceptual frameworks. The Vulnerability Workshop documented, reviewed and discussed the state of methods and models of vulnerability research, analysis and assessment, and set an agenda for future research in this field.

Workshop participants agreed on a first operational definition of vulnerability. They found that vulnerability is a function of a system's exposure to global change stimuli (e.g. climate change, land use change) and of its adaptive capacity. Vulnerability assessment therefore works from two sides: the bottom-up side applies state-of-the-art models of natural systems to describe ecosystem services and their sensitivity to global changes. Simultaneously, in a top-down approach, the adaptive capacity of human sectors is explored in a dialogue between scientists and





relevant stakeholders. Vulnerability as assessed by this approach is the degree to which an ecosystem service is sensitive to global change plus the degree to which the sector that relies on this service is unable to cope with the changes.

The workshop identified the most critical steps in the methodological framework for vulnerability assessment: (1) to include all relevant global change forcing factors and their interactions, e.g. atmospheric changes, N deposition, climate change, land use change; (2) to involve stakeholders from the public and private sectors; and (3) to find ways of quantifying, representing and communicating uncertainty. Strategic partnerships to tackle these highly interdisciplinary research issues were built and reinforced during the workshop. Workshop results are presented on a website dedicated to this purpose - a special issue for a scientific journal is in preparation.

### **Adaptation: Enhancing the Capacity of Developing Countries to Adapt to Climate Change**

Organizers: Richard Klein, Joel Smith (Stratus Consulting, USA), Ferenc Tóth.

The countries and communities most vulnerable to climate change are those that are particularly exposed to hazardous impacts and have limited adaptive capacity. Adaptive capacity is the ability to plan, prepare for, facilitate and implement adaptation measures. It is determined by factors such as economic wealth, technology, information and skills, infrastructure, institutions, equity and social capital. There is an urgent need to better understand adaptive capacity, how it relates to vulnerability and sustainable development and how it can be effectively enhanced. Without such understanding countries run the risk of making ill-advised adaptation investments that do not produce benefits as effectively or efficiently as intended or which are even counterproductive.

The Potsdam Institute for Climate Impact Research and Stratus Consulting (USA) organized a workshop to

develop a research agenda targeted at the adaptive capacity of developing countries. The workshop brought together 45 experts from developing and industrialized countries, NGOs and donor organizations. The research agenda, as well as an edited book volume, will be presented at the World Summit on Sustainable Development (Johannesburg, South Africa, September 2002). The workshop was made possible through sponsorship from the World Bank, the Electric Power Research Institute (USA), the Canadian International Development Agency, the German Federal Ministry for Economic Cooperation and Development /Gesellschaft für Technische Zusammenarbeit and the United Nations Development Programme. Additional support was provided by Environment Canada, the Netherlands Climate Change Studies Assistance Programme and the United Nations Environment Programme.

The research agenda developed at the workshop is framed around six questions, which reflect the importance to “mainstream” adaptation to climate change in sustainable development activities. The six questions are the following.

- How does vulnerability to climate change manifest itself and how should it be defined and assessed to identify adaptation requirements?
- How and in what forms does adaptation to climate change occur, what processes and actors are involved and how can it be modelled?
- What constitutes an enabling environment for implementing adaptation options, what is the role of social capital and how can it be enhanced?
- How can adaptation to climate change be integrated into sustainable development and how can synergies with other policy objectives be created?
- How can priorities for adaptation to climate change be set?
- How can the research capacity and intellectual capital of developing countries be effectively strengthened to address adaptation to climate change?



## Palaeoperspectives on Global Sustainability

Organizers: Martin Claussen, Stefan Rahmstorf.

One important aspect in the discussion on global sustainability concerns the resilience of the natural Earth system to large-scale natural and anthropogenic perturbations (e.g. changes in solar luminosity, volcanic activity, land use, greenhouse-gas emissions, ...). Of particular interest are the last several hundred thousand years. For this period many climate archives, in particular the ice core records, provide a fascinating picture of the metabolism of the natural Earth system. Temperature and greenhouse gases show cyclic variations of long cold periods and shorter warm interglacials, within apparently stable bounds. On the other hand, Dansgaard-Oeschger and Heinrich events show the possibility of very large and abrupt climate swings, while the subtle changes during the "relatively quiet" Holocene need to be well understood in order to put the recent climate change into context.

Approximately forty palaeoclimatologists and palaeoclimate modellers discussed the following topics: lessons to be learnt from the astronomical theory of climate, the role of the ocean in rapid climate change, the problem of leads and lags between climate changes found in Arctic and Antarctic records, and lake sediments as climate indicators. Discussion on palaeoclimate models covered the full range of the spectrum of climate system models ranging from conceptual models of the late Pleistocene (the last ~700,000 years), models of intermediate complexity focusing on simulations of the last glacial cycle, and comprehensive models which are used to zoom into short time intervals of the last glacial maximum.

It was generally agreed that there is no direct analogue for potential future climate change. However, analyses of palaeoclimatic records have proven to be extremely useful in validating climate models - a prerequisite for assessing potential impacts caused by anthropogenic perturbations of the climate system. In particular it was rec-

ognized that terrestrial climate archives are of particular importance. Some terrestrial archives reveal an annual resolution - as shown in the example above which was provided by one of the workshop participants - thereby allowing the reconstruction of decadal climate variability.

## Contributions to Sustainability Science by Applied Mathematics and Software Engineering

Organizers: Rupert Klein, Gerhard Petschel-Held, Nicola Botta, Cezar Ionescu.

A review lecture summarizing key challenges in sustainability science was followed by two sub-sessions focusing on two distinct research areas in which mathematics and computing science can contribute to the field.

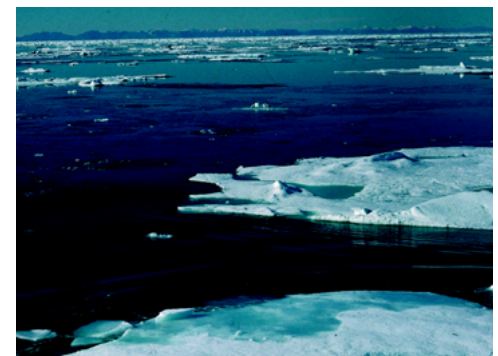
### MATHEMATICAL MODELLING AND COMPUTATIONAL METHODS

Sustainability science deals with regimes where anthropological impacts significantly affect the balance of the Earth system. Since such situations are unprecedented, related computational models cannot generally be validated entirely on the basis of measured data. How can we then achieve reliability of integrated models and their components? This session gave some answers from applied and computational mathematics. The contributions included:

- reduced model equations for geophysical fluid mechanics and their rigorous justification,
- the use of advanced computational models in revealing complex physical mechanisms,
- adaptive numerical methods,
- software engineering challenges in model coupling,
- innovative approaches to data assimilation, and
- thermodynamics concepts in ecological modelling.

### UNCERTAINTY AND SOFT COMPUTING

Many aspects of sustainability science are specified in soft, qualitative terms only. This is particularly true for the social sciences and the linkage between anthroposphere and nature. Furthermore, available data are often



uncertain, vague or incomplete. This leads to intensifying demands for systematic approaches to uncertainty assessments for given, quasi-deterministic models, and for modelling approaches geared towards the exploration of inherently uncertain or "soft" knowledge. The contributions to this session included:

- relative entropy-measures in quantitative uncertainty estimates,
- foundations, classifications, and generalized concepts of multi-valued logics, and
- qualitative and semi-quantitative reasoning, set-valued methods, and possibility theory.

### **Alliances for the Sustainability Transition: The European Climate Forum**

Organizers: Baldur Eliasson (ABB Corporate Research Ltd, Switzerland), Regine Günther (WWF Germany), Klaus Hasselmann (Max Planck Institute for Meteorology, Germany), Carlo C. Jaeger, Martin Welp.

The workshop was the official opening of the European Climate Forum (ECF), which is a non-profit organization carrying out joint studies on climate change. The focus of this workshop was on future orientation in climate change research. It was organized by ECF jointly with PIK and explored the various expectations and conflicts of interest related to climate change issues.

The event brought together key stakeholders and researchers. The stakeholders included selected representatives from the insurance sector, coal industry, renewable energy industry as well as environmental NGOs, the European Union and public media.

The starting point was that different stakeholders have their own underlying assumptions, interests and distinctive expectations concerning the issue of climate change. Some representatives gave more emphasis to adaptation research while others formulated more research needs in, for example, carbon sequestration. To discuss these dif-

ferences parallel break-out group session took place on the following topics:

- climate policy instruments,
- renewable energy technologies and CO<sub>2</sub> sequestration,
- coping with extreme weather events,
- the pioneering role of Europe in climate protection,
- managing uncertainties in climate change research.

In the groups two main questions were addressed. First, what research questions relevant for stakeholders can be identified? Second, are there at present strong differences of views among different stakeholders concerning these research questions?

Results of the workshop were used to develop Joint Forum Studies and to consolidate the working groups. The workshop documentation can be downloaded from the ECF- website (<http://www.European-Climate-Forum.net>).

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