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ESF Forward Look – ESF-COST 'Frontier of Science' joint initiative

Responses to Environmental and Societal Challenges for our Unstable Earth (RESCUE)

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- Forests, their Products and Services
- Materials, Physics and Nanosciences
- Chemistry and Molecular Sciences and Technologies
- Earth System Science and Environmental Management
- Information and Communication Technologies
- Transport and Urban Development
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Conceptual Recycling Symbol with Earth Globe

Contents

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N.B.: In the main body of the report, the words marked with an *asterisk* (*) are defined in the Glossary.

Foreword

The world is currently facing major challenges and crises. One of them is 'global change', sometimes described with reference to the term 'Anthropocene', which was coined about a decade ago by the Nobel Laureate Paul Crutzen. It is an emerging epoch in the history of the Earth, a successor to the 'Holocene' epoch, the last interglacial period recorded. Since the Anthropocene started, the impacts of human activity on the Earth have started to equal the measurable impacts of biogeophysical forces, in speed and intensity, creating a unique situation that poses fundamentally new challenges and requires innovative ways of thinking and acting.

Many global change issues are by now well identified and to a certain extent individually understood. These include global warming, sea level rise, loss of biodiversity, intensification of extreme events, landscapes and land use changes, increasing water scarcity and pollution, ocean acidification, over-fishing, and altered distribution of certain infectious diseases. But it is their multiple combination at local and global levels that brings about a series of major and complex problems.

Such complexity cannot be addressed by the traditional disciplinary scientific approach. An integrated knowledge base and a new set of common practices are required to address these issues. The tackling of the global change challenges must also be of wide societal and individual concern. For this to happen, a deeper and more open dialogue, and integrated cooperation between the research community, policy-makers, society and ultimately private individuals are required.

The RESCUE foresight initiative thus proposes an innovative vision about how to build the transitions towards sustainability through various innovative forms of learning and research. The RESCUE vision is built around the idea of an **open knowledge system**, where knowledge is generated from multiple sources (some of which are scientific) and shared at every stage of its development; and where problems are defined and addressed by society as a whole, not just by scientists, or policy makers.

RESCUE, an ESF-COST 'Frontier of Science' initiative and an ESF Forward Look, is highly integrative, and is supported by 8 Committees of ESF and COST, namely the ESF Standing Committees for Life, Earth and Environmental Sciences (LESC), for Social Sciences (SCSS), for Humanities (SCH) and for Physical and Engineering Sciences (PESC), and the COST Domain Committees for Earth System Science and Environmental Management (ESSEM), for Individuals, Societies, Cultures and Health (ISCH), for Forests, their Products and Services (FPS) and for Food and Agriculture (FA).

This report synthesizes the contributions from approximately 100 experts in 30 countries. It is based on the input of 5 working groups that, from autumn 2009 to spring 2011, focused on: contributions from social sciences and humanities with regard to the challenges of the Anthropocene; collaboration between the natural, social and human sciences in global change studies; requirements for research methodologies and data in global change research; steps towards a 'revolution' in education and capacity building; and interface between science and policy, communication and outreach. This report was also prepared in close cooperation or liaison with other key organisations or initiatives, including the International Council of Science (ICSU), the International Social Science Council (ISSC), the International Group of Funding Agencies for Global Change Research (IGFA) and its Belmont Forum, and the European Alliance of Global Change Research Committees.

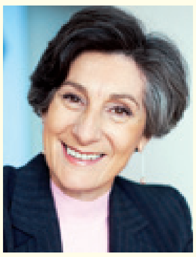
While the RESCUE report was being finalised (in autumn 2011), the International Council for Science (ICSU), within a global alliance of partners, established the 'Future Earth – research for global sustainability' initiative. This international, 10-year collaborative initiative aims to deliver solution-oriented research on global environmental change for sustainability and to provide global coordination for science to respond to the most pressing societal and environmental challenges. This echoes markedly some of the findings and conclusions of RESCUE regarding the global change research agenda setting.

The RESCUE synthesis report is also a European contribution to the preparation of the forthcoming 'Rio+20' United Nations Conference on Sustainable Development (UNCSD, June 2012), which should be a key step forward at a global level for transitions toward sustainability. RESCUE will also contribute to the 'Planet under Pressure - New Knowledge Towards Solutions' Conference (March 2012). While some progress has been made since the publication of the report of the Club of Rome, *Limits to Growth (1972)* and of the report of the World Commission on Environment and Development, *Our Common Future (aka, the Brundtland report, 1987)*, there is still so much to be done in response to the challenges of an unstable Earth.

While the RESCUE foresight initiative was a challenge in itself, as it relies on a truly in-depth dialogue between communities not always familiar with each other, it represents marked progress and we sincerely thank all active contributors, especially the RESCUE Working Group leaders and all Committees involved, and in particular the RESCUE Quality Reference Group.

In conclusion, we warmly encourage all key stakeholders to embark fully on the next RESCUE phase, i.e., the delivery of an open knowledge system for ensuring transitions toward sustainability.

Professor Marja Makarow,
Chief Executive, ESF



Professor Angeles Rodriguez-Peña,
President, COST

Executive Summary

Humankind is facing unprecedented and accelerating global environmental change. So strong is the human influence on the Earth system that many scientists consider that the planet has entered a new geological age called the 'Anthropocene' (the recent age of humans). Our understanding of the environmental aspects of global change has expanded markedly in recent years, but the societal and human aspects of the change have still to be fully explored. There is a need to re-frame global environmental change issues fundamentally as social and human challenges, rather than just environmental issues.

While recognising that there are already moves in the right direction, the RESCUE foresight initiative provides recommendations on how to establish and support a stronger common foundation across natural, social and human disciplines, and how to link global environmental change research more strongly with policy and the wider society. The recommendations are intended for research and education policy makers, funders and researchers. If enacted, they should lead to the development of more integrated, holistic knowledge of global environmental change – knowledge and the related practices that can fully support transitions towards sustainability.

1. RESCUE Background

The "Responses to Environmental and Societal Challenges for our Unstable Earth" (RESCUE)[1] foresight initiative is a joint 'Frontiers of Science' initiative of the European Science Foundation (ESF) and the intergovernmental initiative for European Cooperation in Science and Technology (COST)[2]. The work of RESCUE focused on the following themes:

- Contributions from social sciences and humanities in developing responses to challenges of the Anthropocene (RESCUE **Social-Human**);
- Collaboration between the natural, social and human sciences in global environmental change studies (RESCUE **Collaboration**);
- Requirements for research methodologies and data (RESCUE **Requirements**);
- Education and capacity building - towards a 'revolution' (RESCUE **Revolution**);
- The interface between science and policy, communication and outreach (RESCUE **Interface**).

2. RESCUE findings

Reframing the way global environmental issues are approached will require new questions, new approaches and new ways of thinking in research. For instance, to re-shape human activities related to environmental change, there is a need to understand the roles of culture, values and behaviour in generating global change. This means analysing how problems and solutions are framed at different levels

1. www.esf.org/rescue
2. www.esf.org and www.cost.eu

by different actors. It means examining the interplay between institutions and individuals, and understanding how these interactions can block or drive societal change. **Transforming society** will require people to question deeply-held values and assumptions, a process that can be supported by research.

A vision of an open knowledge system

RESCUE proposes an innovative vision of how to support the transitions towards sustainability with education and research. The vision is built around the idea of an **open knowledge system**. In an open knowledge system, knowledge is generated from multiple sources (some of which are scientific) and shared at every stage of its development. Problems are defined by society as a whole, not just by scientists.

What needs to change?

RESCUE identifies the following specific areas where change is needed, to move towards an open knowledge system.

- **The research framework**
  In Europe, there is no consistent and proactive policy to further collaboration across disciplines. The natural, human and social sciences should be integrated from day one to develop joint questions on global environmental change. To achieve this, a common theoretical and operational framework for research and innovation across disciplines is needed.

- **Transdisciplinarity and new approaches**
  Single discipline research is essential, but transdisciplinary work is required to meet the challenges of an unstable Earth. This means integrated study of behavioural, social and natural processes, with appropriate new research methods. Methodological approaches and data collection protocols should be developed through open consultation. They should be formalised enough to provide the basis for comparative analyses, yet flexible enough to address case-specific issues. Methods are needed that deal appropriately with uncertainty and unknowns, support the use of exploratory agent-based modelling, combine participatory and modelling approaches, explore the roles of human values and behaviour and stimulate change. Data and knowledge acquisition should be increasingly driven by the need for solutions that help the societal transition towards sustainability, for example, by supporting an understanding of human behaviour or facilitating sustainability policy development.

- **The production of knowledge**
  Research and policy communities, and society at large, need to work more closely together to generate and integrate knowledge that is relevant and useful to responding to the challenges of an unstable Earth. RESCUE proposes a Radically Inter- and Transdisciplinary research Environment (RITE) model as a strategy for global environmental change research. This research model is already used in medicine to ensure that all relevant knowledge is harnessed collaboratively from the outset when approaching a problem, and no single discipline maintains overall dominance when developing research programmes.

- **Education and sustainability learning**
  A significantly different approach must be promoted for education and capacity building to deliver the interdisciplinary and systems research required to address global environmental change. The challenges for education and capacity building cannot be met by 'business as usual' approaches or by extrapolating experiences from the past into the future. There is a need to think differently. The latest findings from a range of educational research fields including cognitive science, teaching methods, creativity and collaborative knowledge creation could help to transform learning. These show, for example, that experiential processes encourage individuals to let go of past assumptions and question underlying beliefs. Changes are needed throughout the education system, from pre-school through primary and secondary education to university and beyond, encompassing adult education and capacity building for all sectors of society.

- **Institutions that support the knowledge system**
  Bringing an open knowledge system into existence will require major institutional change. For example, it demands collective problem framing, societal agenda-setting, extended peer review, broader and more complex but transparent metrics for research evaluation, better treatment of uncertainty and values, procedures to ensure that knowledge is 'placed in context', greater flexibility of research funding, cooperation of public and private organisations and stakeholder engagement. New media and new forms of public participation, combined with expanded access to information, will be crucial in building such an open knowledge system. Institutions should encourage and facilitate engagement from all stakeholders in collective societal choices.

3. RESCUE recommendations

The RESCUE initiative makes six recommendations to science policy makers, funders and educators. These will help move towards an open knowledge system.

Recommendation 1: Build an institutional framework for an open knowledge system

Target audience: Science policy makers, science funders

An open knowledge society to tackle the environmental and societal challenges of global change requires an implementation-oriented research agenda and a corresponding institutional framework. Participatory approaches and stakeholder engagement must bring more societal actors into the research and the evaluation processes and must be given credit in both funding schemes and academic careers. New criteria for evaluating 'excellence' in participatory, implementation-oriented processes are required. Long-term support and reward mechanisms are needed for integrative global change research that responds to societal demands.

Recommendation 2: Re-organise research so disciplines share knowledge and practices, and, from the onset, work together with each other and with stakeholders

Target audience: Science policy makers, science funders, research community

Given the need to understand and include the underlying human drivers of global change, there is an urgent requirement for increasing the level of targeted support for those social sciences and humanities that can contribute to this effort. Research to support transitions to sustainability must be interdisciplinary and transdisciplinary, beginning with a collective framing process that includes scientists from natural and social sciences and the humanities as well as actors from civic society, the private and public sectors. The Radically Inter- and Transdisciplinary Environment (RITE) model for global change research needs further development and then widespread implementation.

Recommendation 3: Initiate long-term integrated demonstration projects

Target audience: Science funders, research community, practitioners, science policy makers

A network of long-term integrated studies is required in order to encourage experimentation with different approaches for analysing and building the capacity of regions to deal with environmental change and achieve sustainability. These studies must also address the human drivers and implications of environmental change in broad empirical contexts. The studies must pay attention to the challenges of including stakeholders in the entire research process. Learning to find a common language and joint problem framing must be evaluated and disseminated widely. The monitoring of these demonstration projects should enhance learning about how research can contribute effectively to sustainability transitions.

Recommendation 4: Develop sustainability education and learning in an innovative, open knowledge system

Target audience: Science and education policy makers, educators

Learning is the central element of an open knowledge society and essential for adapting to the complex and changing human condition in the Anthropocene. Processes are required that engage educators from pre-school through universities and far beyond, including a wide range of other professional areas, in a dialogue about the education and capacity building frameworks and institutions needed for an open knowledge and learning society. The new types of research needed to support sustainability transitions and processes of engagement require new skills and capacities that must be provided by the education system.

Recommendation 5: Respond to the challenges and opportunities created by the internet for an open knowledge system ready for transitions towards sustainability

Target audience: Science policy makers, research community

The internet provides a means of access to knowledge, a repository of knowledge, a research tool and an agora that facilitates the production, diffusion and use of knowledge in responding to societal problems related to global environmental change.

There is a need to discuss the role of the internet in an open knowledge society especially with regard to issues of credibility of knowledge. At the same time, there is a need to embrace the opportunities offered by the internet for creating networks or bringing them together.

Recommendation 6:

Create a dynamic, adaptive and integrated information and decision-support system on global change issues

Target audience: Science policy makers, science funders, research community

While numerous environmental, economic and societal information systems exist, the challenges of an unstable Earth and the development of an open knowledge society call for a dynamic information system that can be regularly and easily updated and that provides a forum for communication. The system would use indicators and markers for experts, decision makers and lay people to inform each other readily about the state of the social-environmental system, the likely short- to medium-term changes, the 'intervention' points and potential consequences of alternative choices.

1. Introduction

Humankind is currently facing unprecedented and accelerating environmental and socio-economic changes. The cause of many of the environmental changes witnessed in the past few decades is human activities: fossil fuel consumption, agriculture, land use change, urbanisation, use of non-renewable resources, transportation and so on. This emerging epoch in the Earth history has been called the 'Anthropocene'* (Crutzen and Stoermer, 2000; Steffen *et al.*, 2011). A holistic understanding of global change* in the Anthropocene has expanded markedly, but societal and human drivers and consequences are still to be fully explored through problem-oriented approaches. The extensive knowledge* base that scientific research has created should contribute to the development of sustainable responses to global change challenges. In particular, the complexities of global change, including the interlinkages between human activities and environmental changes, require studies at scales that resonate with (often) short-term political and long-term societal agendas. Integration of research results from various disciplinary areas has had limited success; stronger common foundations between natural sciences, social sciences and humanities are now needed to establish a really integrated approach from the beginning.

In this context, the Responses to Environmental and Societal Challenges for our Unstable Earth (RESCUE)[3] foresight initiative was established as a joint 'Frontiers of Science' initiative of the European Science Foundation (ESF) and the intergovernmental initiative for European Cooperation in Science and Technology (COST)[4] to:

- propose processes for natural sciences, social sciences and humanities to improve in a medium- to long-term time frame their ability and capacity to work together, in order to respond to the pressing policy and societal needs;
- articulate science questions related to global change and especially those of a transdisciplinary nature, or of major society-driven relevance;
- explore effective, new approaches towards truly integrated, interdisciplinary science, and to facilitate the 'revolution' in education it requires.

RESCUE was organised around a series of thematic activities. These were carried out by four working groups and one task force. The membership of these groups is listed in **Annex 1**. The abbreviated titles of these groups are provided in brackets below and used in this report to indicate sources of material. The groups focused on:

- contributions from social sciences and humanities with regard to the challenges of the Anthropocene (**RESCUE Social-Human**);
- collaboration between the natural, social and human sciences in global change studies (**RESCUE Collaboration**);
- requirements for research methodologies and data (**RESCUE Requirements**);
- steps towards a 'revolution' in education and capacity building (**RESCUE Revolution**); and
- the interface between science and policy, communication and outreach (**RESCUE Interface**).

This report is largely based on the individual thematic reports of these groups.

Through its analyses and recommendations, RESCUE aims to enable the scientific communities, together with a large range of stakeholders, includ-

3. See www.esf.org/rescue
4. See www.esf.org and www.cost.eu

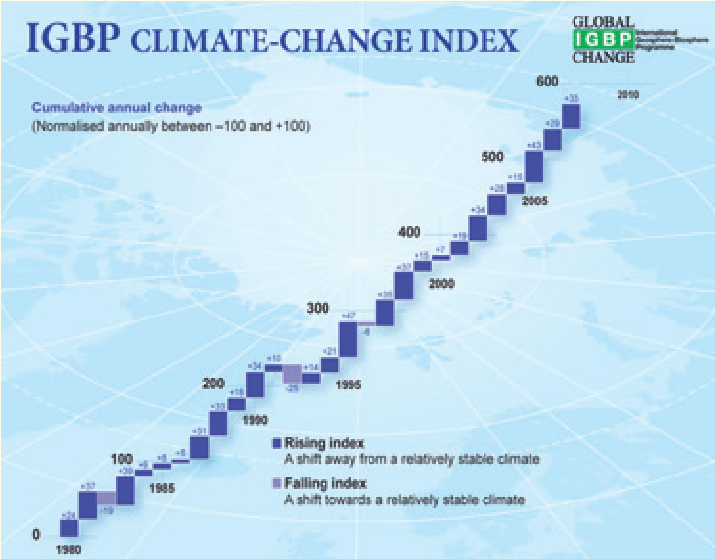


Figure 1.
Two recent examples of current, partly integrated approaches to consider some of the global change issues: IGBP ***"Climate-Change Index"*** brings together key indicators of global change: atmospheric carbon dioxide, temperature, sea level and sea ice (tinyurl.com/6n9f2e3), and IHDP ***"Earth System Governance"*** approach, which emphasizes the role of institutions and governance in relation to global change issues (www.ihdp.unu.edu/article/update-3-2009).

ing policy makers, to develop medium- to long-term strategies for future research activities and applications. It is anticipated that RESCUE will have positive impacts on research to support transitions to sustainable development*, especially in Europe where its efforts have primarily been focused, through its emphasis on a common strategic understanding, improved coordination of scientific endeavours, new approaches at the science-policy-society interface and capacity building.

The RESCUE activities included a kick-off meeting in Rueil-Malmaison, France, in September 2009, followed by virtual and face-to-face meetings as well as a few other dedicated activities of the working groups and task force. An alignment workshop was held in Ispra, Italy, in June 2010 and an integration workshop took place in Antwerp, Belgium, in December 2010. Finally, there was a stakeholders' conference in Brussels, Belgium, in May 2011. The RESCUE work has been coordinated by a Scientific Steering Group composed of the leaders of the Working Groups and chaired by Professor Leen Hordijk and Professor Gísli Pálsson (**Annex 1**), and monitored by a Quality Reference Group (**Annex 2**). The coordination of this joint initiative has been led by Dr Bernard Avril at the European Science Foundation.

It was recognised at the outset (RESCUE, 2009) that the challenges set out by RESCUE have also been taken up by diverse actors and institutions*, including an earlier ESF Forward Look on Global Change Research conducted in 2002 (ESF, 2002). The 2002 exercise addressed the themes of a) collaboration between the natural and social sciences; b) the interface between the science and policy domain; c) the requirements for monitoring and data; and d) capacity building. Since the 2002 report, which essentially set an agenda for Earth System science with a focus on Europe, there have been substantial developments in the ways that social sciences engage with the issues of global environmental change, and in the interdisciplinary dialogues between the natural and social sciences. RESCUE was therefore devised with much deeper engagement by researchers active in the domain of the human drivers of and consequences of global change. The RESCUE initiative also focuses much more on what needs to change in the way that research and education are funded and organised, so that the challenges of an unstable Earth can be addressed.

The RESCUE foresight initiative is a further contribution to international debate about research[5] for global sustainability* such as the 'Future Earth – research for global sustainability' initiative[6] derived from the 'Earth System Science for Global Sustainability' visioning process, led by the International Council of Science (ICSU), with involvement of the International Social Science Council (ISSC)[7], and the Belmont Challenge (ICSU, 2010b; IGFA, 2011)[8]. At the same time that RESCUE was carrying out its work, ICSU and ISSC engaged

5. For more information about research on sustainability see, for example, Jäger (2009), www.essg.eu, www.visionrd4sd.eu, or sustainabilityscience.org. Recent overviews of sustainability assessment purpose, methodologies and practices are provided by Frame and O'Connor (2011) and Singh *et al.* (2009).
6. www.icsu.org/earth-system-sustainability-initiative
7. See www.icsu.org and www.issc.org
8. Developed by the Belmont Forum/IGFA Council of Principals, www.igfagcr.org/index.php/challenge

Figure 2.
RESCUE word cloud

in a visioning process on global change research for global sustainability, involving a broadly-based scientific community. This process identified five closely related grand challenges (ICSU, 2010a) – Forecast, Observation, Thresholds, Responses and Innovation. The visioning process also emphasised that a transition process was required (ICSU, 2010a, p. 6), from research dominated by the natural sciences to research involving the full range of the sciences and humanities. The process also recognised that dealing with the grand challenges requires systemic approaches at various levels (global, regional, local) that attribute a central role to human activities, values and behaviour. ISSC is now engaged in a more comprehensive global change mapping and scoping exercise within the international social science community.

It is noteworthy that, while the present RESCUE report was being finalised (Sept.-Oct. 2011), the International Council for Science (ICSU), within a global alliance of partners, decided to establish the 'Future Earth' initiative. This will be a 10-year international collaborative initiative that aims to effectively deliver solution-oriented research on global environmental change for sustainability and to provide global coordination for science to respond to the most pressing societal and environmental challenges. This echoes markedly some of the findings and conclusions of RESCUE regarding the global change research agenda setting.

A key target audience for this report is the community of research and education policy makers and funders at national and European levels, who are best placed to implement the recommendations. It is also of interest to all the contributing scientific communities. The report begins by examining the challenges posed by an 'unstable Earth' with reference to the main foci of RESCUE: interdisciplinarity*, inclusion of the social sciences and humanities, transdisciplinarity*, methods, tools and data, capacity building and the interfaces between science, policy and society. This is followed by a vision of an open knowledge system* in which these challenges are addressed. A knowledge system organises the production, transfer and utilisation of knowledge. Numerous actors and institutions are potentially involved: scientists, policy makers, industry and business leaders, other societal groups (including civil society organisations) and citizens. The report then addresses the main barriers to achieving this vision, which leads to a set of recommendations on meeting the challenges of an unstable Earth.

2. The Challenge of an Unstable Earth

Research over the last two decades has documented that the Earth is undergoing major environmental and socio-economic changes (see, for example, Steffen *et al.*, 2004; Rockström *et al.*, 2009; Reid *et al.*, 2010). Climate change, land degradation, deforestation, biodiversity loss and changes of water quality and quantity are prominent examples of global environmental changes. The intensity and rate of change for many of these examples have never been recorded in the most recent geological era, the Holocene, or even in the Quaternary (IPCC, 2007). Globalisation, demographic changes, the scarcity of food, energy and raw materials and the widening gap between rich and poor are examples of socio-economic trends that are closely linked with the environmental changes. Furthermore, processes such as climate change or biodiversity loss could lead to a number of irreversible tipping points*, including the dieback of the Amazon rainforest and decay of the Greenland ice sheet (Lenton *et al.*, 2008). Despite agreements reached almost 20 years ago at the UN Conference on Environment and Development in Rio de Janeiro, little has been achieved in putting the planet onto a sustainable track. The 'Rio+20' United Nations Conference on Sustainable Development (UNCSD)[9] should be a key step forward for the transitions toward sustainability. This RESCUE foresight initiative aims to contribute to such transitions.

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Figure 3.
Two examples of global change issues:
(above) land degradation and desertification; (below) water pollution.

In addition to the many 'really global' issues, however, it is also important to focus on local problems. For instance, the triple shock that hit Japan in 2011 (earthquake, tsunami, nuclear meltdown) is a marked example of the importance of the interactions within the physical environment and the fragility of our technologies and infrastructure. How could one anticipate and mitigate the risks associated with such cascading effects of a natural disaster or extreme event on a society which relies heavily on technology, without the proper involvement of many research disciplines? The newly formed Integrated

9. www.uncsd2012.org, *and for instance,* ec.europa.eu/environment/consultations/pdf/report_un_2012.pdf, www.earthsummit2012.org, *and* EEAC (2011)

Research on Disaster Risk (IRDR)[10] project could be a new test-bed for evaluating the human and societal capacity to respond to multiple stressors and for improving it in the short term, through an open, reflexive, adaptive mechanism.

Global change challenges have been described in the literature as 'wicked problems', a term that refers to problems that are difficult or impossible to solve because of incomplete, contradictory and changing requirements that are often difficult to recognise (Rittel and Webber, 1973; Frame, 2008; Brown *et al.*, 2010). Moreover, because of complex interdependencies, the effort to solve one aspect of a wicked problem may reveal or create other problems. Long-term environmental challenges, which are commonly also global, have been defined as "public policy issues that last at least one human generation, exhibit deep uncertainty exacerbated by the depth of time, and engender public goods aspects both at the stage of problem generation as well as at the response stage" (Sprinz, 2009, p. 2; CCSP, 2009). This points to the long time-scales and structural uncertainty inherent in global environmental challenges and to the difficulties that can arise when complex problems are formulated and hamper success at the response stage (e.g., van der Sluijs *et al.*, 2005). The uncertainities related to the complexity of the global environmental change and the human actions have been extensively examined (e.g., Funtowicz and Ravetz, 1990; Funtowicz and Strand, 2011), especially as they play an important role at the science-policy and science-society interfaces (e.g., van der Sluijs, 2006; Pregernig, 2006; van der Sluijs, 2010; Koetz *et al.*, 2011).

Since the environment is increasingly refashioned by human activities[11], there is a need to radically reframe global environmental problems as fundamentally social – moving beyond the traditional, narrow confinement in both academic and public discussions of the 'environment' to the 'natural' domain. While such a reframing presents massive challenges for scholarship, public understanding and engagement, governance* and policy making, it is the only meaningful way to go. It is the precondition not only for the mitigation of environmental problems and for societal adaptation to the unavoidable ones but also for the broader task of reconceptualising the human condition in the Anthropocene epoch. The term 'Anthropocene' has been proposed in reference to an emerging fundamentally new epoch in planetary history, a successor to the current Holocene epoch. Given that the impact of human activity is now of the same magnitude as biogeophysical forces, this creates a completely novel situation posing fundamentally new questions, including issues related to ethics, culture, religion and human rights, and requiring new approaches and ways of thinking, understanding and acting. The challenges are societal, not just scientific.

Overall, the work of the RESCUE working groups and task force has pointed to a number of deficits in the science/research/education system, which makes it difficult or even impossible to meet the challenges of an unstable Earth. These are discussed in this section.

Interdisciplinarity in global change research

Disciplinary specialisation has been the basis of scientific progress certainly since the 19th century; Karl Pearson described the need for discipline-based research *per se* in his book, *The Grammar of Science*, first published by Walter Scott in 1892. Disciplinary specialisation will remain one of the productive divisions of knowledge labour in the future (as described, for example, in the medical field by Toby Gelfand [1976] and discussed in many other studies). It has been noted, however, that disciplinarity sometimes has a restrictive inertia of its own, not least through the tendency of academic elites to seek to 'protect their turf', which needs to be overcome

10. www.irdrinternational.org
11. See, for instance, Landscape in a Changing World – Bridging Divides, Integrating Disciplines, Serving Society. ESF-COST Science Policy Briefing #41, 2010. 16p.

or counteracted. This point has been emphasised in a previous ESF report, *The Future of Knowledge: Mapping Interfaces* (ESF, 2010), partly drawing upon Lloyd (2009). Real-world problems do not conform to disciplinary divides. Large problems call for contributions from many angles and, very often, complex problems cannot be understood and indeed solved by one scientific discipline. Global change research is one such field that clearly requires contributions by academics and practitioners from many disciplines and sectors.

Various terms are used to describe interfaces between research fields (see **Annex 3**[12]). While calls for research funding often cite 'interdisciplinarity' as a desired methodology for large research projects, it may not be clear what is intended, either to the research team writing the proposal, or to the reviewers assessing the proposals and teams' combined strengths. In addition, Klein (2010) gives an overview of the different forms of interdisciplinarity in US universities, varying from informal networks to recognised fields and institutes. The lack of standard and/or uniform definitions across the funding bodies and research institutions is an issue that must be addressed and **Annex 3** proposes definitions to be applied.

Cooperative and integrative efforts in global change research are nothing new. From early reports including that of the Club of Rome (Meadows *et al.*, 1972; 1992; 2004) onwards, research has combined the insights of many disciplines. In nearly all domains of global change research, the role of humans is a key factor as a driving force, a subject of impacts, or an agent in mitigating impacts and adapting to change. While advances have been made in the conceptualisation and practice of interdisciplinary global change research in fields such as climate change and urban sustainability, approaches have tended to frame interdisciplinarity as depending on individual researchers taking the initiative, rather than understanding that complex problems which cut across disciplines may require new epistemological frameworks and methodological practices that exceed any one discipline.

A review by **RESCUE Collaboration** of how the concept of interdisciplinarity is used by various research organisations for global change research reveals that there is no consistent and proactive policy to further collaboration across disciplines, although there are examples of policy and practice. At the first Global Change Open Science Conference in Amsterdam in 2001, participants from more than 100 countries signed the Amsterdam Declaration on Global Change. This called for a new system of global environmental science that "(...) will draw strongly on the existing and expanding disciplinary base of global change science; integrate across disciplines, environment and development issues and the natural and social sciences" (Moore *et al.*, 2001). In response, four international global change research programmes,[13] initiated in the 1980s or 1990s, formed the Earth System Science Partnership (ESSP)[14]. Within this partnership, the research examines the structure and functioning of the Earth system* including the changes taking place and their implications for global and regional sustainability (Leemans *et al.*, 2009). Many other sustainability or development-related projects and integrated approaches have been put in place in the last few decades, by academic researchers and teachers, but also by practitioners in the field and by local development and resources managers. Much has been learned from those too [15]. The 'Future Earth – research for global sustainability' initiative should be a useful, new step in this matter.

Although there are laudable examples of interdisciplinary global change research (see, for example, below) the present situation is not fully fit for dealing with global change challenges. One major reason is that interdisciplinary global change research is not yet widespread. At most universities and other (academic) research institutions, as well as in funding bodies, the monodisciplinary approach has the upper hand. Furthermore, proponents of interdisciplinary global change research at times relegate human and social science research to an auxiliary, advisory and essentially non-scientific status. Social science and humanities research should now feed deeply into global change research to further our understanding of human-environment interaction (Crumley, 2007; Lövbrand *et al.* 2009; ISSC-CIPSH, 2010). This should include scholars dealing with ethics, culture, religion and legal issues. This would also open up new areas and new ways of interdisciplinary collaboration between (already interdisciplinary) global change research and fields not yet involved. Moreover, interdisciplinarity is too often not integrated from the start. The natural, human and social sciences should be inte-

12. Based on personal communication from Professor Karl Georg Høyer (Oslo University College), on definitions in DEA (2008), as well as on further communication from the RESCUE Collaboration WG and the RESCUE QRG. See also Bhaskar *et al.* (2010).

13. DIVERSITAS (www.diversitas-international.org), IGBP (www.igbp.net), IHDP (www.ihdp.org), and WCRP (www.wcrp-climate.org)

14. www.essp.org.

15. See, as starting points, learningforsustainability.net, www.sustainability-literacy.org and vlsearch.org/VLsearch?form=extended&qprev=sustainability

grated from day one to develop joint questions on which they work together. To address the challenges above, a common theoretical and operational framework is needed for interdisciplinary research issues.

Research mechanisms are needed that support the identification of agreed, shared and co-created interdisciplinary research agendas (for example, the seed-corn, sometimes referred to as 'sand-pit', funding of the joint UK Research Councils' Programme on *Rural Economy and Land Use*[16]). This funding has revealed that successful interdisciplinary working requires an acceptance between representatives of different disciplines of the need to provide opportunities for scientists to learn one another's languages, with 'translation' being a prerequisite for the development of shared research agendas (Bracken and Oughton, 2006).

Moving towards transdisciplinarity

In order to avoid potentially catastrophic changes and to build on opportunities to improve human well-being of the current and future generations, there is an urgent need to make changes at the interface between science and policy, and indeed between science and society as a whole (e.g., KLSC, 2011). This requires open cooperation between the science community and all others with relevant knowledge for contributing to solutions for the complex problems of sustainability. Such cooperation is rare today.

Transdisciplinary research (see, for instance, Bergmann *et al.*, 2005; Boix Mansilla *et al.*, 2006; Guggenheim, 2006; Krott, 2004) is currently emerging in the research landscape as an approach that focuses on a problem that is, as described by Wickson *et al.* (2006, p. 1048) "'in the world and actual' as opposed to 'in my head and conceptual'". The authors further argue that this implicitly assumes the notion of creating change and contributing to solutions, based on the integration of different disciplinary methodologies and, ideally, epistemologies, which involves collaboration with stakeholders and the broader community. According to Wickson *et al.* (2006, p.1053), transdisciplinary research [and thus by definition education] processes emphasise the importance of reflexivity:

> *"When researchers become engaged in the problem they are investigating, assumptions of objectivity will inevitably come into question. This means that it becomes important for the researcher to reflect on how their own frames of reference/values/beliefs/assumptions etc. have shaped the conceptualization of the problem, as well as the development of the method of investigation and the solution."*

An example of interdisciplinary success
(Source: RESCUE Collaboration)

Interdisciplinarity can be found within one centre/institute that covers several disciplines and sometimes between different monodisciplinary centres/institutes that form together a multidisciplinary consortium. An example is the Centre for Environmental Sciences of Hasselt University (Belgium), a multidisciplinary centre with biologists, chemists, doctors, economists and lawyers. They consider one of their finest examples of successful interdisciplinary research as their research on the remediation of soils contaminated with heavy metals. Biologists look at the possibility of phytoremediation (a technique using trees/plants to take up the heavy metals), chemists look at the possibilities to use the trees/plants to produce something else, such as biofuel and/or biochar, economists look at costs and benefits (for different trees/plants), mainly to convince farmers to put these specific trees or plants on their contaminated land, and lawyers look at the legal possibilities of cleaning up a soil with phytoremediation and of using the 'contaminated' trees/plants as biomass to produce biofuels.

More information: www.uhasselt.be/cmk-en

There is broad agreement that sustainability research seeks to understand the interactions between nature and society (Ziegler and Ott, 2011), is highly diverse in its forms (e.g., Spangenberg, 2011) and has to overcome the linear model of knowledge production, within which "science proposes, society disposes" (Guston and Sarewitz, 2002, p.95). Sustainability research is hence part of what Gibbons, Nowotny and colleagues term Mode 2 knowledge production that takes place in the context of application and provides "socially robust knowledge" (Gibbons *et al.*, 1994; Nowotny *et al.*, 2001). Accordingly, sustainability research is conceptualised as co-production of knowledge*, the 'co-' standing for a process of engagement of academic and non-academic knowledge producers (Lemos and Morehouse, 2005; Robinson and Tansey, 2006). The resulting network character of knowledge – in the sense of interlinking knowledges of different disciplines and actors of civil society,

16. www.relu.ac.uk

the private sector, and public agencies – is accentuated by Cash *et al.* (2003), speaking of "knowledge systems for sustainable development". Such a knowledge system* spans the boundary between science and other sectors of society, as well as the gap between knowledge and action. In their analysis of such knowledge systems, Cash *et al.* (2003, p.8086-8) found "that efforts to mobilize S&T for sustainability are more likely to be effective when they manage boundaries between knowledge and action in ways that simultaneously enhance the salience, credibility, and legitimacy of the information they produce". There are alternative methodological and institutional approaches of how to create such knowledge systems or co-production of knowledge, like specialised boundary organisations (Guston, 2001) or transdisciplinary research processes (e.g., Klein, 1996; Pohl, 2008). Three specific points should get due attention in such processes of co-producing knowledge: **problem framing, integration** and **implementation**.

Table 1 points to the differences between different types of research in terms of disciplinary orientation, aims, methods used and approaches taken. Transdisciplinarity is in the right-hand column and much of the research called for in response to the challenges of an unstable Earth is of the implementation-oriented type, bridging the gap between knowledge and action.

Many barriers to effective working across the interface between science and policy and wider society have already been identified – and solutions proposed – by academics and research funders, but they tend to focus on just one dimension or target audience. The challenges of cross-boundary working are also well-recognised outside of the research context: businesses are especially attuned to the need to tackle internal cultural issues because failure to do so has a direct bearing on capacity to meet customer needs.

It is necessary to acknowledge the deeply embedded norms and power relations of the knowledge system in which we currently operate. These relate to the actual structure and functioning of research endeavours within its boundaries – and how these boundaries are managed by researchers and other stakeholders. They also affect the relationships between research and policy makers and, more broadly, between research and the overall society in which science is embedded.

Good Practice Example:
Awards for transdisciplinary research
Location: Switzerland
Main actors involved: Stiftung Mercator Schweiz
Time frame: Initiated in 2003, awarded every 2 years
Description: Every two years, the td-net for transdisciplinary research grants the Swiss Academies award for transdisciplinary research to an outstanding transdisciplinary research project by an individual or a research group. The award amounts to CHF 75,000.
Impact: Provide recognition for those who go beyond their disciplinary boundaries and engage with a wide range of other societal actors in their research.
More information: cms.stiftung-mercator.ch/cms/front_content.php?idcat=134

New tools, methods and data

Global change poses unprecedented challenges to both the science and policy communities, and these are challenges that cannot be tackled with concepts and methods developed and applied in the past. Both the environmental and the social sciences have sought to address these challenges, the former through the development of Earth System science (e.g., Schellnhuber, 1999; Steffen *et al.*, 2004) and the latter through critical analysis of processes of globalisation (e.g., Amin and Thrift, 1994). However, these alternative conceptualisations have not been integrated, despite recognition that new forms of inter- and transdisciplinary knowledge creation, and new forms of inquiry, are needed. In fact, despite the need expressed in the Amsterdam Declaration (2001) to move towards a more integrated perspective, the research agenda of global change programmes continues to be framed and dominated by the natural sciences. In their summary of insights from the ICSU visioning exercise, Reid *et al.* (2010) pointed out that the most pressing research questions were quite different from those that initially shaped global change programmes, and that the social sciences and humanities must play a central role in the next phase of global change research. This becomes all the more necessary as the balance of attention shifts from defining the impacts of human activities on the environment to identifying pathways for societal change.

Research methods are needed that allow integrated study of pertinent, individual/behavioural,

Basic research	Applied research	Implementation- and target-oriented research
Classical sectoral disciplines	Engineering sciences	Sustainability science
Emphasis on expanding knowledge	Product orientation	Goal orientation
Problem definitions and discoveries	Technical concept, products, processes	Holistic solutions and strategies
Mono-disciplinary research	Interdisciplinarity	Inter-, multi- and transdisciplinarity
Top-down methods theory – practice	Top-down and/or bottom-up	Bottom-up and top-down practical research
Teams internal to science organisation	Cooperation with industry	Stakeholder involvement
Education of next-generation scientists	Prototype development	Models and instruments to support decision-making processes

Table 1. The different kinds of research (Source: Moll and Zander, 2006)

social and natural processes and their respective consequences for each other. This suggests a renegotiation of the relationship between the humanities, social and environmental sciences that can foster new research agendas suited to the policy requirements for the challenges of global change. Much has been written on the problems and research questions to be addressed in global change research, but far less attention has been devoted to the requirements for methodologies, methods and knowledge, data to address these challenges. A lack of appropriate methodologies and knowledge is a key bottleneck in dealing with the global change challenges.

There are powerful forces that maintain a strong research focus on the paradigmatic scientific role of climate and climate change, although global change is 'felt' more through real (as opposed to global, average statistical) phenomena that are local (such as water and food quality and availability), and there are other global challenges (such as biodiversity decline or energy and raw material availability). There are also deeply embedded assumptions that physical-numerical, computational models constitute a core technology to support policy, and that quantitative data are to be prioritised relative to qualitative evidence, information and value-laden judgement. Incorporating human values, environmental ethics and social justice into the conventional paradigm for analysis requires a radical adjustment of worldview and scientific method (e.g., Hardin, 1968; KLSC, 2011). There are also key assumptions about the relationship between science and policy (see also the previous section) – a belief that 'science speaks truth to power' remains embedded in spite of the evidence of a much more nuanced, convoluted and globally diverse set of relationships.

Methodologies in global change research need to be evaluated according to their inclusiveness and an absence of *a priori* framing that prevents the integration of some kinds of knowledge. In this respect the dominance of large simulation models in global change research has to be assessed critically. Such models follow largely a positivist approach[17] and exclude certain traditions in the humanities and social sciences that follow more an interpretative paradigm. The latter paradigm emphasises embeddedness in contexts shaped by cultural, political, economic, social and institutional factors. It often employs qualitative methods and adopts an 'action research'[18] perspective rather than that of

17. Positivists believe that social reality is stable and can be observed and described from an objective scientific viewpoint (Levin, 1988), i.e., without interfering with the phenomena being studied. Interpretivists contend that only through the subjective interpretation of and intervention in reality can that reality be fully understood. They look for meanings and motives behind people's actions like behaviour or interaction with others. They criticise positivists, because statistics and numbers cannot tell much about human's behaviour and sociology is not seen as a science. See www.sociology.org.uk/revgrm5.pdf, pjlor.files.wordpress.com/2010/06/chapter-3-draft-2011-04-152.pdf, www.justinkitzes.com/pubs/Khagram2010_EnviroCons.pdf, www.is.cityu.edu.hk/staff/isrobert/phd/ch3.pdf

18. Action research is a reflective process of progressive problem solving led by individuals working with others in teams or as part


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the detached observer. An erroneous presumption classically applied in natural science or engineering is that integration of social science knowledge into global change studies can be through addition of socio-economic processes into these model structures. However, this raises critical issues about both the viability of representing these processes in numerical form, and the implications of doing so for the policy application of model simulations. What are required are innovative methodologies that support an integration of the interpretative and the positivist research paradigms, which offer complementary rather than conflictive perspectives. In this regard, there are experiments with the storyline and simulation (SAS) approach (Alcamo, 2001 and 2008), the reflexive interventionist/multi-agent-based ('RIMA') scenario approach (Wilkinson and Eidinow, 2008) or with a reflexive governance (Voß *et al.*, 2006) concept. The TRANSvisions[19] project is another recent example using assessments, scenarios and models, for backcasting exercises, on the topic of sustainable mobility in Europe in 2050. The term 'backcasting' was coined by John Robinson (Robinson, 1982; Dreborg, 1996; Robinson, 2003) as a futures method to develop normative scenarios and explore their feasibility and implications, by means of a participatory process. The concept of backcasting is central to a strategic approach for transitions towards sustainability (for instance, Carlsson-Kanyama *et al.*, 2007; Quist, 2007).

Only through the analysis of the behaviours of individuals and groups within socio-ecosystems can scientifically sound methods for exploring and understanding the emergent properties of such complex and adaptive (evolving) systems be developed. In turn, it is only through the understanding of the emergent properties of the socio-ecological system that the capabilities needed for any approach targeting global change can be developed. Developing capabilities to analyse and, possibly, to simulate the behaviour of individuals and groups within different societal structures and environmental contexts appears as one of the most promising avenues for understanding and acting on the drivers of and barriers to change. This includes developing improved understandings of the ways that values, beliefs and worldviews influence perceptions of and responses to environmental change (O'Brien and Wolf, 2010). In this regard, as pointed out by Balbi and Giupponi (2010), there is an increasing awareness that global change dynamics and the related socio-economic implications involve a degree of complexity that is not captured by traditional approaches based on equilibrium models. In particular, such analyses of human-environment systems do not consider the emergence of new behavioural patterns. This eventually leads to a flawed policy making process that relies on unrealistic assumptions (Moss *et al.*, 2001). Caballero (2010) recently added "that the current core of macroeconomics – by which I mainly mean the so-called dynamic stochastic general equilibrium approach – has become so mesmerized with its own internal logic that it has begun to confuse the precision it has achieved about its own world with the precision that it has about the real one. This is dangerous for both methodological and policy reasons". Within economics, a substantial rethinking is underway regarding the capability of mainstream methods to deal with the complexity and the dynamics of current – and future – societal systems. Similar statements are made for other research fields related to global environmental change and its human drivers and consequences (e.g., Stern *et al.*, 1992; Fraser *et al.*, 2003; US-GCRP, 2003). The multiple crises that humans are currently facing (e.g., financial, economical, depletion of water, food and energy resources, climate change, pollution) make

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of a 'community of practice' to improve the way they address issues and solve problems. Action research can also be undertaken by larger organisations or institutions, assisted or guided by professional researchers, with the aim of improving their strategies, practices and knowledge of the environments within which they practise (see, for example, Greenwood and Levin, 1998).
19. www.mcrit.com/transvisions

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it even more urgent to consider all these in a systemic way. There is a need to search for solutions not only across disciplines, but also across problem areas, and any sustainability research, agenda and governance should consider carefully the linkages between problem areas. The denial of the complexity of global change issues, as sometimes observed, or attempts to over-simplify can also lead to problems, such as putting blame on the wrong people or developing a conviction that there is no need to act.

Discrete or statistical data on human population characteristics and behaviours are widely collected through censuses and surveys. Data on human behaviour often rely on inference and may run up against confidentiality concerns. In addition, even data on population characteristics vary widely in their quality, completeness and comparability among countries. Other data-related issues include accessibility or availability, temporal and spatial resolution or granularity of social data, the multiplicity of data sources and standards, the high cost of commercially produced data, private data protection and/or commercialisation, overall protection of privacy, data loss, and the costs of quality control and long-term archiving of data sets that were 'born digital' and which may have future value as baseline data or for longitudinal analysis. All these issues need to be further considered as part of the challenges and should be thus studied in order to suggest systemic improvements for the mutual benefit of data and information providers or gatherers and users (i.e., modellers, theorists, policy advisors, businesses, general public). Large geographical areas of the Earth lack the necessary density of data coverage for reliable description or modelling by conventional methods (notably, but not exclusively, in Africa). Even in economically wealthy countries, this density may be threatened by short-term policy exigencies. As well as the spatial and temporal coverage being uneven, there is often a problem of inter-temporal comparability. Indeed, innovation may itself be as much a barrier as a solution, since there is a considerable need for continuity and reliability in data streams rather than frequent short-term innovation and instability, especially because short-term, low-risk innovation is often prioritised by academia and research funders. This is true even of remotely-sensed environmental data, but is even more marked for social science data, where long-term monitoring has been less systematic, funding for data collection is limited, and where there may even be a tendency for research funders and policy makers to alter data protocols in order to frustrate the very longitudinal study that is required.

Data constitute the raw material of scientific understanding and science (and methodological) innovation is, in part, data driven (WDC, 2007; CODATA, 2007)[20]. New sources of data and associated tools, such as crowd-sourced and citizen-science data, participatory science e-data, SciScope[21], and ever higher resolution satellite imagery, high temporal resolution of *in situ* data measurements and quasi-real time acquisition and processing, are driving innovations in science and also in praxis (Dozier and Gail, 2009). Data-sharing principles being developed under the INSPIRE[22] Directive in Europe, under the Group on Earth Observations (GEO) globally (GEO, 2009) and in other contexts are paving the way to greater accessibility with fewer restrictions. The increasing number and sophistication of satellite instruments has led to an exponential

20. The World Data Center system (WDC; www.ngdc.noaa.gov/wdc and www.icsu-wds.org) of the International Council for Science (ICSU) has been established in the early 1960s to guarantee access to solar, geophysical and related environmental data. It serves the whole scientific community by assembling, scrutinising, organising and disseminating data and information. Recognising a worldwide demand for useful, reliable and readily available scientific and technological data, in 1966 ICSU established a Committee on Data for Science and Technology (CODATA; www.codata.org) to promote throughout the world the evaluation, compilation and dissemination of data for science and technology and to foster international collaboration in this field.
21. www.sciscope.org
22. Infrastructure for Spatial Information in the European Community (INSPIRE), inspire.jrc.ec.europa.eu

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Figure 4.
The atmospheric pollution caused by the Eyjafjallajökull eruption created many disturbances in the European transport industry and in associated human activities. The direct cost of this 6-day event in 2010 was estimated to about 2.5 billion Euros.

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Figure 5.
The soil and water pollution caused by waste management industry is more local but contributes also markedly to the environmental degradation and the loss of good living conditions.

increase in data availability to scientists working on climate, biophysical and biogeographical systems, and have brought about significant innovations in these disciplines. To be sure, these data can also be useful to social scientists (de Sherbinin *et al.*, 2002; de Sherbinin, 2010), but our ability to make inferences about individual behaviour from satellite observations is still limited and depends heavily on field-based observations and, critically, census and survey data. Furthermore, much can be learned about socio-ecological systems and human vulnerability and resilience* to global environmental change by integrating data from the social and natural sciences in a spatial framework (e.g., Balk *et al.*, 2005; de Sherbinin, 2009; Dilley *et al.*, 2005; O'Brien and Wolf, 2010).

At present, not many shared databases and protocols exist in global change research, and particularly in the social sciences. This set of data resources is far from being comprehensive, integrated or interoperational. One initiative to improve this situation is promoted by a group of scholars working on the governance of social-ecological systems*, who have started to assemble in a loose network to develop the foundations for such shared databases and protocols for analysis. In order to analyse more broadly the potential and limitations of such undertakings, more support is required for infrastructure and methodological development and incentives are needed for wide participation in such joint efforts.

Many global change case study analyses have been conducted in isolation. Hence it is quite difficult to come to general insights and to be able to conduct comparative analyses. Some scholars have suggested what can be called a diagnostic approach taking into account complexity in a systematic fashion (e.g., Grimm *et al.*, 2005; Alessa *et al.*, 2006; Ostrom, 2007; Smith and Stirling, 2007; Young, 2008; Norberg and Cumming, 2008; Pahl-Wostl, 2009). Such an approach should support context-sensitive analysis without being case-specific and thus not transferable. This is a major methodological challenge since active stakeholder involvement is rather driving case studies towards becoming entirely case-specific. A requirement for comparative analyses would be to develop and agree on methodological approaches and data collection protocols that are both sufficiently formalised so that they provide the basis for comparative analyses yet sufficiently flexible to address case-specific issues and developments. In this direction, there are some attempts to produce a typology of knowledge integration in case studies of transdisciplinary research (e.g., Zierhofer and Burger, 2007).

The need for an "education revolution"

The important role of education was acknowledged 20 years ago in the following statement: "Education [...] should be recognized as a process by which human beings and societies can reach their fullest potential. Education is critical for promoting sustainable development and improving the capacity of the people to address environment and development issues." (Agenda 21, 1993, Chapter 36). The World Bank's Global Knowledge Learning launched in 1996 is another early demonstration of the belief that knowledge in democratic governance is a key factor for poverty reduction and sustainable development (Blindenbacher, 2010).

The potential consequences of human impacts on the environment have provoked many arguments for urgent and unprecedented responses, from calls for transformations in energy systems and a shift to more sustainable ways of living, to calls for geo- or bio-engineering projects and authoritarian eco-regimes (e.g., Brown, 2009; Shearman and Smith, 2007; Victor *et al.*, 2009). While it is clear that part of the problems the world is currently facing are linked to some intentional or unconscious (historical and present) choices toward a technological, engineering-based society, and that some or parts of those problems could be addressed through some technological solutions, it is now understood that society is heavily dependent on technology-associated natural (finite) resources (e.g., energy, water, land, rare-earth elements) and on unfairly used or distributed human resources (e.g., cheap labour, lack of work safety, child work). Society is thus facing new (i.e., never experienced before) challenges that require a strong, integrated research mix of natural, physical, social sciences and humanities. Underlying many of these arguments is a growing recognition that responses to the complex environmental and social challenges of the 21st century require a radically different approach to education and capacity building. Education appears to play a critical role in developing understanding and building capacity to act, i.e., to address the complex, non-linear and potentially irreversible environmental changes associated with human activities (RESCUE, 2009). There is, however, concern that most universities and research institutes are limited in their delivery of the type of interdisciplinary or transdisciplinary knowledge needed to address environmental problems; they certainly are not delivering as quickly as scientific findings suggest is necessary.

Since the 19th century, a powerful and highly successful model for education and capacity building has predominated in the Western world, which has been exported to all corners of the world. This model has been built around the demands of the industrial era, and includes the development of disciplinary expertise, academic autonomy, and transmission of knowledge and information to develop a society that promotes material and technological progress and achievement. In recent years, this model has (in many parts of the world) included a greater role for the private sector, with an emphasis on standardisation, learning* outcomes, and performance indicators. As Sterling (2001, p.40) argues, "[t]his managerial approach in education reflects mechanistic beliefs in determinism and predictability – which leads in turn to a belief in the possibility and merits of control." The approach favours educating people to adapt to change, rather than building their capacity to shape and create change (Sterling, 2001).

However, in light of scientific and social advances, strong evidence is accumulating that a new phase of systematic education and capacity building in sustainable development/sustainability will be needed, which integrates a diversity of methods and goals at all levels (e.g., Hesselink *et al.*, 2000; Adams, 2006; Hoffman and Barstow, 2007; Jörg *et al.*, 2007; Esbjörn-Hargens *et al.*, 2010; Jones *et al.*, 2010). From the practices of pre-school and school education to institutions for higher education, and from the learning and knowledge diffusion activities of scientific research to adult learning and skill acquisition, the challenge is to synthesise and apply the latest findings from a range of fields, including psychology (e.g., Gilbert, 2011), cognitive science, teaching methods, creativity and collaborative knowledge creation to transform education such that it can meet the challenges and uncertainties of global environmental change. New approaches to research and education are now seen as the foundation for building the capacity to respond to environmental change. Suggested approaches include Radical Inter- and Transdisciplinary research Environment (RITE) (**RESCUE Collaboration**), and a greater emphasis on systems analysis, higher-order thinking and 'resilience thinking' (Walker and Salt, 2006; Reid *et al.*, 2008; Fazey *et al.*, 2007; Sterling, 2010; Krasny *et al.*, 2011). Knowledge, it has been argued, can no longer be seen as separate and disconnected from actors and policy processes, and new methods and approaches to collecting, managing and interpreting data are regarded as necessary to understand dynamic changes.

In short, it is becoming clear that 'business as usual' or 'more of the same' will no longer be suitable, and that nothing less than a 'revolution' in education and capacity building is needed to confront the challenges posed by global environmental change. The changes in education and capacity building that are needed in response to contemporary and future environmental and social challenges will require more than adjustments in current educational systems, research funding strategies and interdisciplinary collaborations. While such interventions may be important and necessary, they represent 'first order changes' or 'doing more of the same, but better' (Sterling, 2001). Instead, **RESCUE Revolution** argues that there is a need to promote second- or even third-order changes that involve re-thinking systems by "seeing things differently" (Sterling, 2001, p.28). In other words, the revolution in education and capacity building is not simply a technical problem, defined by Heifetz *et al.* (2009) as a problem that has known solutions that can be implemented through current know-how, but also is an adaptive challenge that can only be addressed through changes in people's mindsets, priorities,

Examples of interdisciplinary education and learning initiatives
(non-exhaustive list)

Interdisciplinary schools and initiatives established to promote education for sustainability include:
The Institute of Human-Environment Systems at the Swiss Federal Institute of Technology, Zurich, Switzerland; the ETH Sustainability Network, Zurich, Switzerland; the Oslo Sustainability Initiative at the University of Oslo, Norway; the Stockholm Resilience Centre, Sweden; the 'Strategic Leadership towards Sustainability' International MSc programme at BTH, Sweden; the STEPS Centre at the University of Sussex, Brighton, UK; the Cambridge Sustainability Practitioner Programme and its Cambridge Sustainability Network, UK; the International Research Institute in Sustainability at the University of Gloucestershire, Cheltenham, UK; the Institute for Advanced Sustainability Studies, Potsdam, Germany; the German Social Ecological Research (SÖF) Programme; the International Center for Transdisciplinary Research in France; the Université Interdisciplinaire de Paris, France; the BABEL – 'Construire les notions-clés du développement durable' seminars, Reims, France; the INRIA Sustainability Transition, Environment, Economy and local Policy research network, France; the 'Dossiers et Débats pour le Développement Durable' association, France; the Doctoral School Sustainable Development at the University of Natural Resources and Life Sciences, Vienna, Austria; the Centre of Transdisciplinary Cognitive and State-System Sciences, Austria; the Research Institute for Managing Sustainability, Vienna University of Economics and Business, Austria; the newly formed European Network for Environmental Ethics; the School for Sustainability at the Arizona State University, USA; the Institute for Sustainable Solutions at the Portland State University, USA; the Institute for Resources, Environment and Sustainability at the University of British Columbia, Canada; the 'Social and Ecological Sustainability' PhD programme, University of Waterloo, Canada; the Transdisciplinary Doctoral Programme focusing on Complexity and Sustainability Studies 'TsamaHUB' in Stellenbosch University, South Africa.

beliefs, habits and loyalties (Hoffman and Barstow, 2007; Reid *et al.*, 2008; Heifetz *et al.*, 2009; Kegan and Lahey, 2009; Jones *et al.*, 2010).

Many institutions of higher education have already responded to the call for more interdisciplinary research (see examples in box). Interdisciplinary research programmes have been fostered by the international global change research community of the International Council for Sciences (ICSU) and capacity building for the international global change research community by, e.g., the Global Change System for Analysis, Research and Training (START)[23] organisation. But reforms have been relatively slow, and in some cases even counter-productive. For example, many of the initiatives consist of 'clip together' course offerings that do not include a coherent framework for understanding complex processes of social-ecological systems, including deeper issues linked to psychology, consciousness/cognitive studies, cultural studies, religious studies and so on. The fact that much has been tried, with less than satisfactory results, suggests that it may be necessary to seek answers outside of the traditional responses and institutions. In other words, innovative approaches to solving persistent problems are needed.

Often the repeated calls for more interdisciplinary global environmental change research, new framings of environmental and societal problems, more stakeholder participation and so on represent a continuous revolution around an unchanging and even unrecognised or invisible axis. This axis, one could argue, represents a core set of unquestioned assumptions that lead to only small and step-wise changes (including a few new models of good practice in interdisciplinary research on sustainability). Drawing on this image of revolution, it appears that the majority of existing approaches to education are primarily spinning on an unquestioned and invisible axis. Most approaches treat the challenge for education and capacity building as a technical problem that requires adjustments in current practices. To move beyond this particular type of circular revolution, it may be necessary to identify an alternative approach, i.e., changing the axis by questioning current beliefs and assumptions regarding the delivery of education.

Significantly, RESCUE recognises that "[t]he dualism of nature and culture [...] both obstructs our understanding of what is global change and weakens our ability to address those challenges" (RESCUE, 2009). This dualistic worldview that separates humans and environment represents the

23. www.start.org

Good Practice Example: Barefoot College in Rajasthan, India

Location: India
Main actors involved: A collective of urban educated persons and professionals registered as Social Work and Research Centre, rural communities
Time frame: Established in 1972
Description: This is an example of new initiatives on South-South learning using different languages, including art and non-scientific jargon now emerging in the field of sustainability. In the Barefoot College in Rajasthan, India, illiterate women learn about the use of solar technology and then share their knowledge with other illiterate women.

In the meantime, Barefoot College's philosophy has spread over a network that has grown organically throughout India and even Africa. The women at Barefoot College learn how to solve their everyday problems in a sustainable way and strive for a more balanced society. It is funded through grants and donations received from the Government of India, international funding agencies as well as private foundations, and through income generated through own sources.
More information: www.barefootcollege.org; vooruit.be/en/page/1491; thoughtsandtalks.so-on.be

ontological basis for modernity and positivist science (e.g., Castree, 2005). The questions are: what kind of capacity is necessary to move beyond this dualism? What kind of education is needed to play a role in building this capacity and changing the way that problems are understood and addressed? The predominant approaches to the problems discussed above often fall prey to this dualism, and this observation drives us to look for the roots underlying such approaches. Bohm (1992) pursued such an inquiry and found incoherence in perceptions and the fragmentation of thought to be at the heart of such issues.

There is clearly a need for a comprehensive and strategic approach to capacity building to address complex global change problems (e.g., Leemans *et al.*, 2009). The key challenges for research identified through the ICSU visioning processes and Belmont forum will require an enhanced research and education capacity to address them through interdisciplinary research (Reid *et al.*, 2010; ICSU, 2010b; IGFA, 2011; KLSC, 2011).

University education systems have been the main channel for developing and disseminating understanding of global environmental change. Yet these systems are undergoing enormous changes in response to social, economic and technological changes. For example, "[t]eacherless or virtual-teacher learning is described by enthusiasts as a revolution in the making" (Giridharadas, 2009). The high levels of specialisation and the division of labour promoted by the industrial revolution have led to reductionist understandings and actions by individuals and organisations. Different types of reforms have been proposed and tested (see, e.g., Corcoran and Wals, 2004). However, it has been argued that:

> *"sustainability does not simply require an 'add-on' to existing structures and curricula, but implies a change of fundamental epistemology in our culture and hence also in our educational thinking and practice. Seen in this light, sustainability is not just another issue to be added to an overcrowded curriculum, but a gateway to a different view of curriculum, of pedagogy, or organizational change, of policy and particularly of ethos."*
> (Sterling, 2004, p. 50).

Necessary institutional change

The challenges of dealing with persistent problems of unsustainability require a new, open knowledge system. This means, as discussed throughout this report, integrative research, integration of knowledge, increased public awareness and interest, collective problem framing, plurality of perspectives, better treatment of uncertainty and values, extended peer review, broader and transparent metrics for evaluation, dialogue processes, societal agenda setting and stakeholder engagement. All of this will require major institutional change. The kinds of institutional changes required for an open knowledge system to respond to sustainability challenges are elaborated further in the remainder of this report. Here one example is highlighted – changes in the way that global change research is evaluated and supported.

Current processes used by the institutions bestowed with authority, funding and peer-review capacity to decide what is 'good science' or what type of science needs to be performed are often characterised by a particular vision of knowledge and of science that tends to be rather exclusive than inclusive. Furthermore, departmental and disciplinary segmentation, while important for the understanding of the parts, is not enough for understanding complex adaptive or evolving systems in their entirety.

Western, modern science can be understood as a system of rules, commitments and relationships adopted by particular organisations to achieve multiple goals and interests which do not always or necessarily relate to the actual quest of knowledge discovery. Current science and technology is mostly used to expand markets (e.g., most of the EU R&D investment is framed under the label of 'knowledge for growth')[24], push national economic competitiveness and support military and corporate power. Science, rather than being simply and only an activity oriented to the understanding of the world around us, is, above all, an institutional enterprise and one of the main sources and expressions of power and authority. Many of the organisational arrangements in which research is carried out, and where the scientific professions operate, are thus not fit for or are in conflict with what is needed to develop an open, diverse but at the same time integrated science which aims to support sustainability.

Collaboration in research is supported by specific funding mechanisms. Among many funding mechanisms available for European research, the European RTD Framework Programmes, probably more than any other single mechanism, have contributed to bring together nearly all natural and social science disciplines in integrative efforts. However, the European Framework Programmes, with the possible exception of the European


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Research Council, have not yet fully harnessed the humanities as well as certain parts of other sciences badly needed for successful global change research. New research activities, such as the UK 'Living With Environmental Change' (LWEC)[25] programme, the French 'Climate-Environment-Society'[26] research consortium, the French 'Global Environmental Changes and Societies' (CEP&S)[27] programme and the German 'Megacities – Megachallenge: Informal Dynamics of Global Change'[28] programme, promise to increase funding for radical interdisciplinarity by programmatically cutting across all disciplines and there are also good examples of successful interdisciplinary collaboration for International Polar Year projects[29].

A number of reports for the EC Directorate General for Research & Innovation have recommended increased funding for interdisciplinary research, while also deploring the inadequacy of current levels of integrated research responses to grand challenges (Lyall, 2011). The 'Monitoring

24. See, for instance, in connection with the Lisbon Agenda, the work of the EC Expert Group on Knowledge for Growth (K4G, 2005-2009), ec.europa.eu/invest-in-research/monitoring/knowledge_en.htm

25. www.lwec.org.uk
26. www.gisclimat.fr/en
27. www.agence-nationale-recherche.fr/programmes-de-recherche/appel-detail/changements-environnementaux-planetaires-et-societes-cep-s-2011
28. www.megacities-megachallenge.org/index.html
29. ipy.arcticportal.org

European Trends in Social Sciences and Humanities' (METRIS) report[30] highlighted the unfulfilled potential of human and social science for global change research and commented: "The type of interdisciplinary research that is often needed to tackle major societal issues cuts across the distinction between the natural and the social sciences and, increasingly, the humanities: climate change or pandemics, for instance, are issues that necessitate a wide-ranging cooperation between natural and social scientists. This requires 'deep' forms of interdisciplinarity that are achieved rather than given, and require significant efforts from researchers." (Holm *et al.*, 2009, p. 35).

In many systems, there is a disconnection between (often) short-term political will and declarations of good intentions and their actual implementation, mainly because of weak leadership. Adjusting policies, funding scheme criteria and processes often takes a long time (e.g., EEAC, 2008). The need to follow the political intention combined with the path dependency and inflexibility of an administrational system, and the external constraints sometimes observed, results in tensions within funding schemes. Changing the funding schemes is a complex administrative procedure (white papers, consultations, drafts, approvals from various committees). As a result, 'interdisciplinarity' is simply added to the list of criteria for funding schemes basically developed to support and initiate disciplinary research (i.e., the list of criteria becomes inconsistent).

In addition, the review process, crucial to the quality of research, needs (often voluntary) reviewers. The pool of reviewers does not yet reflect the interdisciplinary requirement. Hence it happens that sophisticated interdisciplinary proposals are rejected based on the review of a reviewer not aware of what constitutes quality and innovation in interdisciplinary research.

As a result of these concerns, a redesign of funding schemes as well as administrative processes (including adjusted qualification profiles for staff and reviewers and others) as well as re-thinking of structural features will be necessary in order to ensure that interdisciplinary proposals are taken seriously. The argument here is not that funding agencies should get rid of disciplinary research funding schemes – these are important as well. Interdisciplinary funding needs different structures and procedures than monodisciplinary funding.

30. www.metrisnet.eu and ec.europa.eu/research/social-sciences/pdf/metris-report_en.pdf

3. The RESCUE Vision

The challenges of an unstable Earth, including those related directly to the collective, human and individual responsibility for having 'destabilised' the Earth system, and the deficiencies in the research, science-policy and science-society linkages, education and capacity building spheres, and the related empowerment required, have been discussed in the previous sections. They inspired the RESCUE working groups to develop a vision of a knowledge system that deals more effectively with the persistent problems of unsustainability that are becoming increasingly clear.

The RESCUE Vision is based on an innovative, open knowledge system for the Anthropocene. This means integrative research, integration of knowledge, collective problem framing, plurality of perspectives, better treatment of uncertainty and values, extended peer review, broader and transparent metrics for evaluation, dialogue processes, societal agenda-setting, and stakeholder participation. All of this is supported by formal and informal education and capacity building.

An open knowledge system is proposed with the following characteristics:

- New integrative forms of knowledge, knowledge production, and interfaces between knowledge and its utilisation that are open to stakeholders' **participation** are essential for understanding and acting on societal issues, fostering socially relevant innovation, and making effective policy to address global change impacts.
- Scientists have a critical **responsibility** to **collaborate** openly in knowledge co-production with all other stakeholders and can do so in a variety of ways.
- **Learning** is essential to adapting to a complex, changing condition and requires learning to learn and learning to co-produce and implement new and prior knowledge in an iterative loop of learning, doing and reflection.
- Changes in formal and informal **educational institutions and practice** from pre-school through the university and beyond are needed to support new knowledge systems and new research processes that are integrative, transdisciplinary, collaborative and capable of innovation for societal well-being.

An open knowledge system

The RESCUE Vision transforms the current dominant framing of knowledge as a closed, uniform, linear and placeless system of insights and aptitudes to an adaptive framing that takes into account, promotes and, whenever possible, integrates a diversity of patterns of knowledge and modes of interaction produced for multiple purposes and under different representations. In addition, dealing with the global unsustainability challenge also requires overcoming many cultural dualisms such as those between nature and society that still exist in the dominant modern Western worldview (O'Riordan, 2004; see also the full report of **RESCUE Social-Human**). This requires attitudes and approaches to science that focus on a holistic perspective of the complex human-social-ecological interactions and dynamics.

Within the new vision of knowledge (see Figure 6 and the report of **RESCUE Interface**), the general ambition is to protect, promote and whenever possible integrate the diversity of languages, concepts, models and forms of knowledge ways that support transitions to sustainability (Tàbara, 2005).

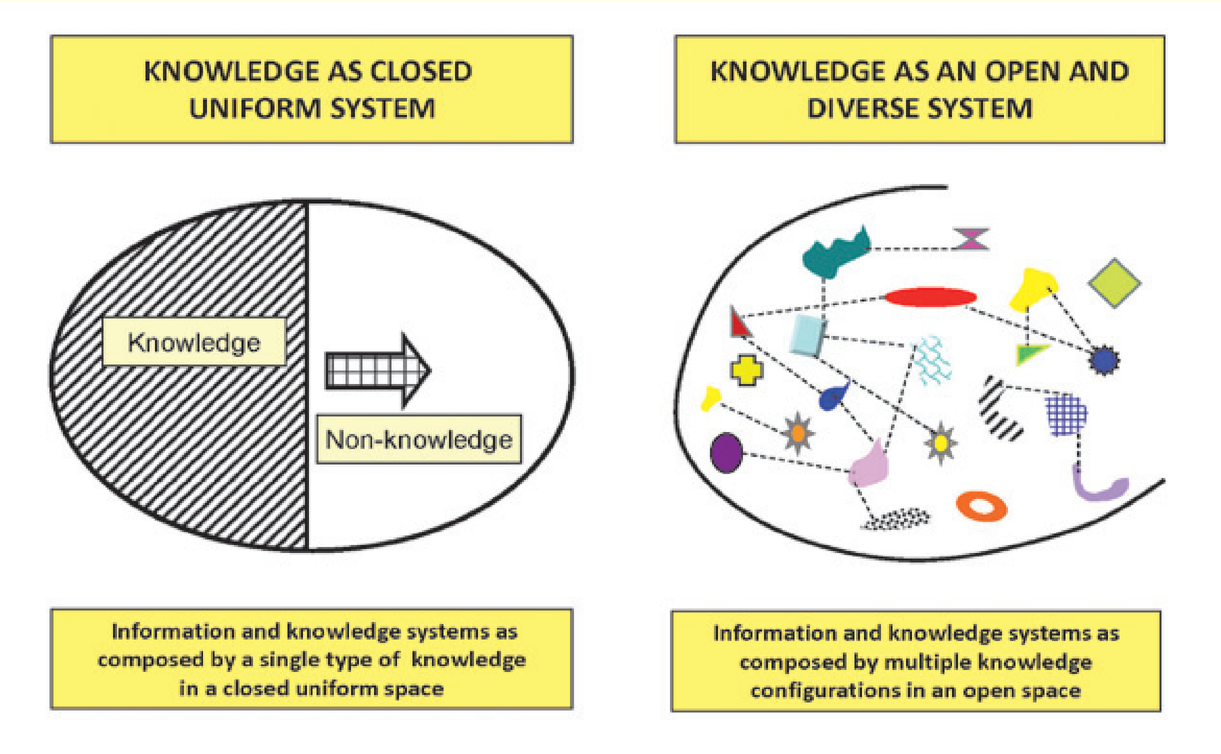

Figure 6. The vision of an open knowledge system (right-hand side) compared to the current practice (left-hand side) (After Tàbara, 2005).

The two illustrations in Figure 6 represent in a simplified way the current knowledge system and a vision of an open system. On the left-hand side, all different types of knowledge (e.g., scientific knowledge from different disciplines and knowledge of stakeholders) are assumed to be the same. It also assumes that the progress of knowledge is like a filling a glass of water – once the glass is full everything is known. On the right-hand side, different clusters of largely indivisible and irreducible nature-knowledge-practices emerge from long-term, social-ecological systems learning and evolution. These clusters represent processes in which a particular problem (e.g., energy supply in a village, water quality in a watershed, climate change impacts in a mountain region, mobility in an urban area, etc.) is discussed among a range of stakeholders, all of whom bring their different kinds of knowledge into the process. The knowledge is integrated in order to reach a common understanding of what the problem really is and which underlying drivers need to be tackled. The process can then evolve to again integrate knowledge in finding and testing solutions to the problem and learning about what works and what does not work. New findings give rise to new questions, new sources and forms of knowledge that need to be addressed and integrated. Integration thus can be improved to address certain questions, problems as well as potential solutions, many of these are overlooked under the current way of integration (i.e., left-hand side of Figure 6) because what is integrated on the right-hand side are contextual sources of knowledge, as well as different ways of framing problems, rules of organisation and possible solutions which may or may not be useable in other contexts.

Likewise, the arrow on the left-hand side represents the idea, widely embedded in the academic world today, that the advance of knowledge requires its translation into a single way of representation. As discussed in the section above on the need for transdisciplinarity, the arrow on the left-hand side represents the mode of 'science finds the answers and tells the others what to do', whereas on the right-hand side, science is integrated in each cluster and provides one of the sources of knowledge needed to describe the problem and find the solution.

A radically interdisciplinary and transdisciplinary environment

Within the vision of an open knowledge system, **RESCUE Collaboration** emphasises the design and funding of a Radically Inter- and Transdisciplinary research Environment (RITE). Each of the clusters in Figure 6 has to be both interdisciplinary and transdisciplinary (see definitions in Annex 3). In addition, the shaded part on the left-hand side of the open knowledge system requires interdiscipli-

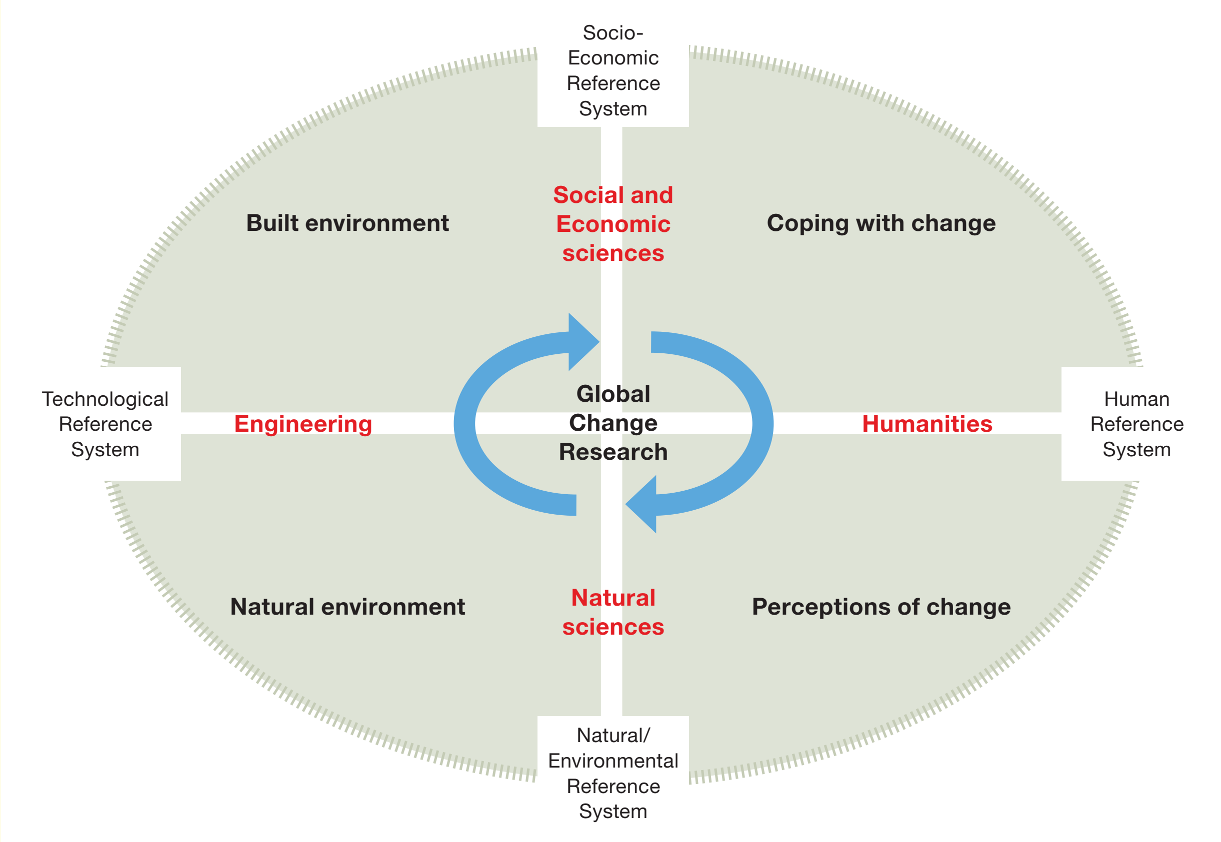

Figure 7.
The reference systems of Global Change Research.

nary and transdisciplinary research in addition to the traditional forms of disciplinary knowledge production and integration.

The vision underlying the RITE framework is that natural sciences, physical sciences, social sciences, humanities should be integrated from day one when tackling sustainability issues. None of these sciences should be hegemonic, which means that no particular science or discipline maintains a prerogative when developing a research programme. In particular, it is important in global change research (see Figure 7) that other perspectives than natural sciences are allowed to identify research priorities that are aligned with fundamental research questions within their disciplines in order to develop global change research as a research field at the cutting edge.

To understand and cope with global change all fields of human knowledge must be harnessed. Scientific division of labour means that knowledge is compartmentalised in different reference systems but the challenges of sustainability, resilience, vulnerability, adaptation and mitigation are best addressed via dialogue across reference systems.

The RITE framework provides a translational research strategy/model for global change research. The translational research model is already used in medicine to achieve the same results as medical science does for patients. Within RITE, it means that the Earth is the patient that should be kept healthy and not just healed. The framework is an invitation to all disciplines (including strong disciplinary research fields and innovative interdisciplinary endeavours) and domains to collaborate in a fully-rounded and integrated view of environment and its place in nature and society.

A central concern – deep integration of underlying aspects of human activities

The integration of human activities as well as the underlying aspects such as culture, values and behaviour into global change research implies:

- understanding the role of culture, values and behaviour in generating and adapting to global change;
- analysing the factors that influence how problems arising from global change and solutions to deal with them are framed at different levels by different actors and how such framing is mediated to lead to a dominant societal response or lack of response;
- understanding the interplay between institutional factors and human agency and its translation to barriers and drivers of societal change;

• analysing potential and limitations to steer system transformations and requirements for supporting a reflexive process* of societal change that requires questioning deeply-held values and assumptions.

The RESCUE Vision requires that methodologies and structures are in place that would weave these insights into a fabric that may serve as the foundation for robust, sustainable, societal action. This includes:

• wider conceptualisation and classification of uncertainties, increased acknowledgement of uncertainty, and greater focus on different methods to represent and communicate uncertainty and to reduce it and/or mitigate its impacts (especially in terms of potential damage and of probability of occurrence);
• use of exploratory agent-based modelling* to examine an increasing wide range of social-environmental problems, issues;
• a combination of participatory and modelling approaches;
• methodologies and approaches that explore the roles of human values and behaviour and stimulate changes;
• interdisciplinary research agendas amongst multidisciplinary groups of scientists.

To do justice to the complexity of the human and societal issues to be addressed and the richness of insights coming from social sciences and humanities, the RESCUE Vision suggests that it will be important although not sufficient to develop a new generation of models where processes linked to human activities are better represented.

Adopting a global perspective by comparative regional analyses

Instead of conducting case studies in isolation, the RESCUE Vision adopts a diagnostic approach taking into account complexity in a systematic fashion. Such an approach supports context-sensitive analyses without being case-specific and thus not transferable. A requirement for such comparative analyses is to develop and agree on methodological approaches and data collection protocols that are both sufficiently formalised that they provide the basis for comparative analyses yet sufficiently flexible to address case-specific issues and developments. Some nodes of the open knowledge system are regional analyses designed so that comparison and thus learning are enabled.

Data and knowledge for global change research

As noted above, the RESCUE Vision builds the capacity for developing knowledge bases that allow general yet context-sensitive insights to be drawn from a wide range of case studies. Furthermore, the RESCUE Vision responds to the continuing need to invest in the traditional social science data streams through census taking (or registries) and survey research, and to make these data available, as far as feasible, without restriction, in spatial formats at the highest resolution possible (without violating confidentiality), and at minimal or no cost to the user. Also, continuity in satellite data streams is maintained.

Data needs in the RESCUE Vision are increasingly driven by the need for solutions to the problems of unsustainable development. This reflects the vision of an open knowledge system "driven primarily by a desire to engage with issues in the non-academic world, issues that do not primarily emerge in disciplinary journals, or in academic discourse alone, but often have to do with fundamental dilemmas or crises in society that do not seem to lend themselves to easy solution by traditional approaches or methods of analysis" (Robinson, 2008). Data systems that do not contribute to praxis are increasingly difficult to justify in a resource-constrained world in which risks from environmental, economic and social spheres are multiplying. Thus, data collection and analysis supporting an understanding of human behaviour and action support policy development. For example, a transition to sustainable greenhouse gas emissions at 80% below current emissions (Allison *et al.*, 2009) involves strong government intervention with regards to subsidies, investments, direct regulation and tax policy. Thus data from focus groups, surveys, observations of individual and household behaviour obtained in an open knowledge system are gathered to support such policies. An open knowledge system is closely connected to issues of freedom of information and intellectual property rights and relies in particular on freely accessible data.

Building capacity for an open knowledge system

Sustainability cannot be imposed. It can only be learned and it can only develop effectively when a large proportion of the human population changes its behavioural patterns to more sustainable practices. The vision of an open knowledge system provides a vast process of sustainability and social learning (e.g., Scholz *et al.*, 2006; Tàbara & Pahl-Wostl, 2007; Stibbe, 2009; Scholz, 2011; see also Annex 4) to empower individuals and groups from all sectors of society, not just the scientific community, to tackle the urgent problems of accelerated global change. Learning to do new things, do them in different ways, and producing different types of knowledge forms for diverse purposes are stimulated in the clusters of the open knowledge system. Fundamental to a vision of future knowledge and learning is the recognition that change is occurring over temporal and spatial scales that require continual change in societies now and far into the future. Consequently, learning to learn and adaptive thinking are the goals of the trajectory of learning through everyone's lifetime. Furthermore, for the RESCUE Vision to be achieved, much more attention is needed regarding the questions of what education means in an open knowledge system and what place knowledge bases and repositories and methodological analyses (e.g., Singh *et al.*, 2009) have in such a system.

Five potential foci of the revolution in education and capacity building that is part of the RESCUE Vision have been elaborated.

a. *Building capacity to do the interdisciplinary and systems research required to understand and manage the challenges of an unstable Earth*
The framework for interdisciplinary and transdisciplinary research discussed above requires an increased commitment in the RESCUE Vision to the development of **interdisciplinary education and curricula** and accreditation criteria.

b. *A transformation of the university education system that trains potential researchers and educates citizens about resilience and sustainability*
In the RESCUE Vision institutions of higher education support education that has comprehensive integrity. This involves teaching different stories, including stories that enable students to interact more creatively with the emergent processes of the universe, providing not only the understanding and sense of direction for sustainability, but also evoking the energy needed to create this new situation (O'Sullivan, 2004). Efforts to promote higher-order thinking and 'resilience thinking' through problem-oriented teaching methods (Fazey, 2010; Walker and Salt, 2006) are also a priority.

c. *Creating awareness of sustainability in the primary and secondary education systems*
The RESCUE Vision calls for an ambitious programme for inquiry-based science education, whereby students (ages 5 to 16) are "encouraged to develop a sense of wonder, observation, and logical reasoning" (Léna, 2009).

d. *Capacity building and education of researchers in developing countries*
The RESCUE Vision responds to the need for the EU and national agencies "to develop multilateral efforts to aid capacity building in the developing world, including the support of young researchers" (ESF, 2002, p.7). Developing countries are a 'special target audience' because (i) the primary integrated societal challenge is that of livelihoods and development, and (ii) institutions in developing countries could be easily guided toward transdisciplinary approaches to knowledge production. This allows the developing countries to develop an endogenous narrative and agenda on what is needed for capacity building.

e. *Education of the public at large and the politicians*
Education is a key element in any response to environmental change (Qvortrup, 2009). The RESCUE Vision thus encompasses adult education and lifelong learning, as well as the promotion of transdisciplinary thinking and learning about responsibility (Kegan and Lahey, 2009; Esbjörn-Hargens *et al.*, 2010). Such initiatives are important for the development and maintenance of the clusters of the open knowledge system with broad participation of all layers and sectors of society. This will also contribute to the delivery of long-term political and societal agendas for securing transitions toward sustainability.

4.
Achieving the RESCUE Vision

The RESCUE Vision for an innovative, open knowledge system for the Anthropocene requires deep changes in mind-sets, as well as in the cultural and moral assumptions about what knowledge is, how it is produced, for whom it is, and for what goals. This also requires profound changes in basic dominant attitudes and institutions and the inclusion of other legitimate sources of knowledge in truly global and, simultaneously, local or place-oriented dialogues for sustainability.

The skills and abilities of scientists

The skill-base of many academics and practitioners is not fit to fulfil the RESCUE Vision. In addition to the disciplinary specialisation discussed above, many scientists have a very superficial and incomplete understanding of real-world politics, commerce and socio-economics. Linked to this, scientific training and weaknesses in political culture leave people disinclined and not used to reflecting on their own activities, values and ethics. For the RESCUE Vision to become a reality, the research community must recognise and accept its social responsibility, and acknowledge the political nature of dealing with global change.

In terms of required competences, scientific and methodological excellence is important for researchers, but additional capabilities are needed for achieving the RESCUE Vision. For example:

- humility and openness towards other systems of thought (other disciplines and cultures), world-views and other sources of knowledge, both formal and informal;
- the ability to listen to others, being able to communicate in real (multiple-way) dialogues;
- willingness to acknowledge that the partial knowledge the researcher brings to the dialogue table will be transformed in the discussion process (giving latitude to other people);
- being focused on creating connections;
- procedural and management skills;
- the enthusiasm and ability to learn, rather than impose knowledge;
- avoiding dualisms in the way social-ecological-technical systems are understood, e.g., by appreciating the knowledge embedded in living organisms and their intrinsic value, as a necessary condition for improving the quality of the knowledge on and for sustainability;
- promoting integration between knowledge and practice and integration of science and humanities and enhancing learning by doing and the exchange of experiences and practices, within this new vision of knowledge systems of open knowledge (social-ecological-technical/extended) democracy.
- supporting the empowerment of people, especially those most exposed to local and global environmental changes, through collaborative and sustainability learning.

Communication and collaboration skills are needed as part of the educational experience from earliest childhood through university level, as well as adaptive thinking skills and the ability, disposition and capacities for engaging with and enjoying complex and socially relevant issues; the skills and know-how to work in partnership across diverse governance settings, with training that not only includes methodologies and approaches, but also personal skills such as negotiation, communication and integrative research methods and practices. See Winowiecki *et*

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Figure 8.
Another example of global change issues: warmer temperature and more dynamics atmospheric circulation increase the frequency and intensity of extreme weather events, which in turn affect more severely over-populated low areas: An helicopter is rescuing a coastal resident after the violent "Xynthia" windstorm, which crossed western Europe in late February 2010 and created windstorm-related flash floods, linked to powerful storm surge topped, hitting at high tide. (photo AFP)

al. (2011) for a recent review about interdisciplinary communication.

Incentives for this kind of work are currently very weak, and generally transient – a function of the demand-driven nature of transdisciplinary work. Disincentives for this kind of work are generally strong and deeply engrained in academic culture. Academics and practitioners who do want to work in integrative, engaged ways currently often find themselves 'locked-in' to a complex system of cultural barriers shaped by self-reinforcing processes. These barriers include differences in language and terminology, methodologies and techniques, norms and expectations about research development and dissemination, and the criteria for prestige and self-actualisation. It is often intellectually and practically difficult to move outside of one's own domain of expertise or practice.

In this context, a key process developed by each 'knowledge culture' – usually disciplines, although these do evolve – is the definition of criteria by which research quality is assessed (for instance, Boix Mansilla *et al.*, 2006; Feller, 2006). No scientist wants to produce 'poor quality' work. By definition, the assessment of research that bridges boundaries will be problematic where existing knowledge cultures have agreed on fixed criteria, and a move towards fixed (quantitative) metrics has been a general trend.

Having embarked on the risky enterprise of participatory, integrative, interdisciplinary, user-engaged research, there are still very few career opportunities for those who choose to get involved. Academic institutions and science funders have been slow to provide security of employment in ways that the skills required for this work can develop throughout a career.

Academic institutions

Despite the Bologna Process[31], much of current research and education practice can be regarded as following the closed system model, with its practitioners operating in isolation from each other and from the realities of the world and contributing to the development of a uniform standard of knowledge production procedures and products. Inter- and transdisciplinary knowledge production and a diversity of models of learning and interaction

31. The Bologna Process took place following the Bologna Declaration (1999) that set out a vision for 2010 of an internationally competitive and attractive European Higher Education Area where higher education institutions, supported by strongly committed staff, can fulfil their diverse missions in the knowledge society. (www.ehea.info/article-details.aspx?ArticleId=3 and www.ond.vlaanderen.be/hogeronderwijs/bologna/about)

for sustainable development are still weakly institutionalised compared to traditional disciplinary science, but are the methodological and practical backbone of knowledge as an open system.

There is a need to address the procedural, political, institutional and, last but not least, cultural barriers within and between institutions. This in itself requires that educational institutions take on the mandate for training researchers and practitioners who can deal competently with diversity and complexity in their institutional environments.

Evaluation of academic institutions also needs to include useful measures of the outcomes of public engagement in terms of changes in attitudes, behaviour and policies and thus reward academic faculty and corporate researchers for engaging substantively with the public and policy makers.

Leading institutions such as the Columbia University (USA) Committee on Global Thought (CGT)[32], led by Nobel Laureate Professor Joseph Stiglitz, have recognised *"that many of the world's problems, such as poverty, inequality and governance, fall increasingly in the spaces between academic disciplines."* Taking action, the CGT asks: *"How does a University create Global Citizens"* and *"initially aims to identify underrepresented viewpoints that link the disciplines."* The RESCUE Vision needs to be supported by similar efforts in European universities.

The barriers to both interdisciplinarity and transdisciplinary education are numerous, and have been widely discussed in the literature. These include a combination of structural, cultural and cognitive barriers and problems related to disciplines as social institutions (Buanes and Jentoft, 2009). It has been argued that the structural barriers are the easiest to address, whereas cultural barriers are more persistent: "What makes disciplines so inflexible and interdisciplinarity so difficult is not only that disciplines are formed around one or a few aspect visions, but that they also harbour strong truth perceptions that are so much taken for granted that any empirical test is unnecessary" (Buanes and Jentoft, 2009, p. 451). Overall, the academic institutions should become more adaptive in order to allow the transformation of knowledge for sustainability (e.g., Miller *et al.*, 2011).

For the RESCUE Vision, an educational system must be developed that is closely coupled to interdisciplinary research. The need for strategic focus on interdisciplinary research by universities given a changing global [human and natural] environment is not new. Jantz[33] states: "In response to various pressures for change arising from the present situation, the university will have to adopt a new purpose which may be recognized as a means of increasing the capability of society for continuous self-renewal. With this new purpose in mind, the structure of the university will be determined by the concept of an integral education/innovation system…". Clearly while some European universities already have a strategic focus on educating the next generation of citizens able to contribute effectively to society in a changing global environment, many are still practising 'business as usual'. Sustainability research networks between universities and other educational institutions are spreading and gaining momentum. The Sustainable Development Research Network (SDRN)[34] and the Global University

Good Practice Example:
Master's Degree in Sustainability Science and Policy
Location: Maastricht University, The Netherlands

The new Master of Science in Sustainability Science and Policy (MSc SSP) provides an intensive programme where students will acquire knowledge and skills (competences) to deal with one of the world's most relevant and complex questions: how can we balance ecological, economic and social developments for our present and future well-being? The programme aims to meet the need for scholars who are trained in interdisciplinary and integrative approaches towards sustainable development, enabling them to assess and deal with the complexity involved from a system's perspective. Furthermore, it aims to train professionals who are able to cross 'boundaries' between different disciplines and domains, and that can operate at the interface of science, policy and society.
The Masters programme will create a unique opportunity for students to specialise in sustainability science and policy, and especially in sustainability assessment, through an interdisciplinary curriculum in an international ambience. The MSc SSP is characterised as a 'society-oriented Master'.
More information: www.icis.unimaas.info/education/must/

32. See cgt.columbia.edu/about/mission and cgt.columbia.edu/about/committee

33. www.springerlink.com/content/p8642kgv28147372
34. www.sd-research.org.uk

Network for Innovation (GUNI)[35] are good examples, among many others[36], as they are gathering leading professionals from different areas of sustainable development research, innovation and policy making. For the RESCUE Vision, students need to be brought up in a flexible environment where they feel empowered to be interdisciplinary.

Measuring "success"

The narrow metrics used in most cases in the present knowledge system are not appropriate for an open knowledge system and in any case have known weaknesses. Recognising some of those weaknesses, alternative metrics have been developed in some fields such as the ERIH (European Reference Index for the Humanities[37]) which seeks to avoid biases in terms of differences in publishing cultures, academic disciplines and national languages. Furthermore, bibliometrics show only a weak link between publications and the research budget granted, so for research policy decision makers*, they have limited predictive power. Often, the economic returns on a single piece of work are low and a strong focus on technological or economic gains privileges private over public interests. If 'policy impact' is sought, then the causal links are generally even weaker. Impact factors may produce a simple number, but their derivation can be very complicated (and opaque), and their design and application can be just as value-loaded as peer judgement. In use-oriented research, which often bridges disciplines, metrics such as impact factors can result in errors and misunderstandings, because different knowledge communities have very different publication vehicles (e.g., books or journals), publication rates and norms for citation behaviour and authorship. Furthermore, while scientists may aim to publish in journals with the highest impact factor, these are not necessarily the locations where their work would have the highest societal impact. 'Applied', 'policy-oriented' or 'user-engaged' research is often regarded as a lower-value activity than basic science, and people devote comparatively little effort to outreach and engagement as a result. This situation would have to change for the RESCUE Vision to become effective.

Changing methods and approaches

The current paradigm in global change and sustainability research is frequently based on deeply embedded assumptions that physical-numerical, computational models constitute a core technology to support policy, and that quantitative data are to be prioritised relative to qualitative evidence, information and value-laden judgement. Incorporating human values, environmental ethics and social justice into the conventional paradigm for analysis requires a radical adjustment of worldview and scientific method.

For the RESCUE Vision, knowledge bases have to build on shared concepts or languages and practices. First efforts are on their way to developing such frameworks. Ostrom (2007) suggested organising variables of interest in the study of social-ecological systems in a nested, multi-tier framework. For instance, a management and transition framework was developed by Pahl-Wostl *et al.* (2007 and 2010) to analyse multi-level water governance and management regimes. Both approaches provide a shared language/ontology but have flexibility and permit the analyst to choose and tailor his/her inquiries according to the needs of the issues under consideration. Both approaches rely on a systemic perspective to embrace complexity and a comprehensive representation. This requires an interdisciplinary approach in the social sciences and across the social-natural science interface. Both requirements pose considerable challenges to scientific communities.

Research within the RESCUE Vision would clearly benefit from leaving behind the 'navigation mode' approach based upon modelling and moving to a new exploration mode in which several consolidated approaches would be used. With reference to human agency issues, for instance, the traditional modelling approaches based upon the possibility of validation should be complemented by new exploratory ones which cannot by definition be validated and thus raise new and challenging issues in the field of policy support.

35. www.guni-rmies.net
36. For instance: the Emergence of Social Enterprises in Europe research network (EMES; www.emes.net), the UNU Global Learning Space for Sustainable Development, with Regional Centres of Expertise (RCE, www.ias.unu.edu/sub_page.aspx?catID=108&ddlID=183), the Social Economy and Sustainability Research Network (SESRN, www.msvu.ca/socialeconomyatlantic/english/DescriptionE.asp), the Inter Disciplinary Networking Labs (DiscInNet, www.discinnet.com), the Academic Cooperation Association (ACA, www.aca-secretariat.be), the European University Association (EUA, www.eua.be), the Talloires Network (www.tufts.edu/talloiresnetwork), the DEsign EDucation & Sustainability (DEEDS, arts.brighton.ac.uk/research/sustainability-network/deeds-project) project, the Association for the Advancement of Sustainability in Higher Education (AASHE, www.aashe.org), the Great Transition Initiative (GTI, www.gtinitiative.org), the "Postgraduate Researchers Interested in Sustainability Matters" (PRISM, insight.glos.ac.uk/sustainability/iris/prism/Pages/default.aspx) network.
37. www.esf.org/erih

Societal engagement

The tendency to view 'scientific knowledge' as a truth that needs to be communicated to 'users' often ignores other types of knowledge or perspectives. The move from 'science for society' to 'science with society' calls for a new approach, or what Jasanoff (2003) refers to as "technologies of humility". The RESCUE Vision of an open knowledge system requires broad societal engagement, not just changes in the scientific community. The type of knowledge used to inform decisions that affect global sustainability must be subjected to both scientific and public scrutiny, since they affect society as a whole. Sharing of accountability (e.g., Frodeman, 2011) across different scales of decision making* will require that science and research be included and embedded across a wide range of settings. This will demand flexibility and initiative by all partners, to negotiate learning goals and generate lessons that can be shared amongst all different levels and locations of governance. Regular venues and events for engagement and dialogue, including locations and forms that are familiar and unthreatening to the participants from diverse communities will be required. The open system will need to support a continual search for innovative ways to establish and extend connections that allow individuals, communities and institutions to engage with each other across cultures, disciplines, as well as geography. Social media and interactive entertainment activities can be used to engage people in dialogues in new ways that emphasise collaboration across disciplines, lowering barriers to participation by making spatial separation irrelevant and providing time for reflection in dialogues.

New forms of openness and exposure

Politicians and public organisations have long relied on science as a steering device and legitimising resource for policy decisions (e.g., Ezrahi, 1990). Science is now facing new challenges, in particular through the spread of the internet and interactive entertainment resources. Tensions internal to science are being mediated in and across new settings, porosities and permeabilities. New forms of openness and exposure (see, for example, 'Climategate' and, in another domain, Wikileaks) are emerging, as are new forms of participation and engagement (citizen science, user-led innovation, participatory sensing, crowd-sourcing). Climategate and the issue of what is sometimes called the 'denial of climate change'[38] are of critical importance in this context, partly because they illustrate a collapse of trust between science and the public. This new topic has now generated a vast set of literature and public controversies over the source of global change, the IPCC contributions and processes and the most effective response to global warming. The setup and governance of the recently formed Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[39] has carefully considered those matters related to IPCC exposure, in order to avoid misuse of scientific messages or misinformation from non-experts (e.g., IPBES, 2011; Koetz *et al.*, 2011). For the RESCUE Vision, dealing with a system with multiple sources of knowledge and legitimacy (Orlove *et al.*, 2008) will become a necessity.

Supporting an open knowledge system

Overall, an effective way has to be found to promote best practices in European research organisations to fund activities that could better contribute to achieving the RESCUE Vision.
The support of an open knowledge system will require:

- a wide range of funding mechanisms (e.g., for basic research, applied interdisciplinary research and for transdisciplinary implementation-oriented research);
- support from different public and private organisations;
- extended peer review;
- broader and more complex but transparent metrics for evaluation;
- procedures to ensure that both methods and end applications of knowledge production are 'placed in context', considering both social and environmental aspects.

The current incentive structure in science supports short-term optimisation of individual performance rather than long-term cooperation in teams and networks with shared products. This proves to be a general problem for the scientific community but is particularly detrimental for global change research.

The lack of long-term funding for interdisciplinary research leads to a lack of continuity for the development of methodologies and methods,

38. See for instance en.wikipedia.org/wiki/Climate_change_denial, www.logicalscience.com; www.realclimate.org and the blog: climatedenial.org
39. www.ipbes.net

of data and knowledge bases. If undertaken at all, such work moves increasingly out of universities into large global change institutes or research networks. However, given the huge uncertainties associated with global change, it is unclear which kind of knowledge will prove to be the most relevant for dealing with scientific and policy challenges and the structure of the scientific research community needs to be able to respond to these challenges (CCSP, 2009).

For the RESCUE Vision, the knowledge system must be flexible and responsive to emerging insights. This argues in favour of flexible network structures and associated funding patterns. At the same time, researchers must be able to engage in long-term research activities and cooperation structures that allow exploring and assessing innovative research themes and building the capacity for effective interdisciplinary cooperation. Hence a key task for science policy and science management is to develop the right instruments that support these kinds of self-organising network structures within the RESCUE Vision.

Currently, in most contexts research budgets still tend to reflect the old idea of relegating humans and their impacts to the margin in the grand scheme of things. As a result, a radical effort to redress the balance and to multiply funding for the social sciences and the humanities within global change research is unavoidable for achieving the RESCUE Vision.

5. Recommendations

In order to move substantively and rapidly in responding to the challenges of global change, the RESCUE initiative proposes major changes in the current research paradigm by developing and implementing a broad framework of research and an open knowledge and learning system drawn from the diversity of actors, institutions and intellectual (re)sources in the global human society.

Recommendation 1:

Build an institutional framework for an open knowledge system

Target audience: Science policy makers, science funders

An open knowledge society to tackle the environmental and societal challenges of global change requires an implementation-oriented research agenda and a corresponding institutional framework. Participatory approaches and stakeholder engagement must bring more societal actors into the research and the evaluation processes and must be given credit in both funding schemes and academic careers. New criteria for evaluating 'excellence' in participatory, implementation-oriented processes are required. Long-term support and reward mechanisms are needed for integrative global change research that responds to societal demands.

Good Practice Example:

CoCE – Conservation and Use of Coffea Arabica in the Montane Rainforests of Ethiopia

The project CoCE was conducted in the south-western regions of Ethiopia between 2003 and 2009. It was an Ethiopian-German cooperation involving the Universities of Addis Ababa and Bonn as well as leading institutional partners in both countries. During its seven-year lifetime it developed possible solutions for the wide-ranging problems of conservation and sustainable use of the Ethiopian coffee forests.

To conduct the project as an implementation-oriented project with strong stakeholder involvement and in order to make the results of the project sustainable, an NGO was founded during the third year of the project. This NGO consists of Ethiopian researchers whose personal and professional incentives were not just academic but who wanted to contribute to coffee forest conservation also practically while working in this newly founded NGO.

Four challenges at the science-policy interface – practice of science, too low funding, interference with conventional science careers, and the enormous complexity of the problems – had to be dealt with in the CoCE project. The creation of an NGO by the project demonstrates one way of creating a new interface between knowledge and action.

This example demonstrates the value of a long-term project that involved stakeholders and went beyond the usual remit of a research project to actually implement solutions. This required flexibility from the science funding side and from the researchers. Institutional change is needed so that credit is given for this kind of work in funding and the development of career paths.

More information: www.coffee.uni-bonn.de and www.ecff.org.et

Recommendation 2:

Re-organise research so disciplines share knowledge and practices, and, from the onset, work together with each other and with stakeholders

Target audience: Science policy makers, science funders, research community

Given the need to understand and include the underlying human drivers of global change, there is an urgent requirement for increasing the level of targeted support for those social sciences and humanities that can contribute to this effort. Research to support transitions to sustainability must be interdisciplinary and transdisciplinary, beginning with a collective framing process that includes scientists from natural and social sciences and the humanities as well as actors from civic society, the private and public sectors. The Radically Inter- and Transdisciplinary Environment (RITE) model for global change research needs further development and then widespread implementation.

Good Practice Example:

Lund University Centre for Sustainable Studies

Location: Sweden

Main actors involved: Lund University

Time frame: Established in 2000 on the initiative of the University Chancellor

Description: The Centre is a platform for education, research and cooperation inside and outside academia on problems related to sustainable development. The Research School aims to find new ways of integrating knowledge across the divides between social and natural sciences as well as between critical and problem-solving research. This will be done in the context of major sustainability challenges such as climate change, global health, loss of biodiversity, the global water crisis and land use change. Research on complex issues is usually best pursued in groups where researchers with different but related expertise investigate different aspects of a joint problem. The LUCSUS Research School offers scientific training and a fruitful learning environment where the exchange of knowledge between younger and more experienced researchers is emphasised and developed.

This example demonstrates one of the initiatives to change the research paradigm to integrate knowledge and build capacity in problem-solving. A widespread adoption of such approaches is needed for the RESCUE Vision.

More information: www.lucsus.lu.se/html/about_lucsus.aspx

Recommendation 3:

Initiate long-term integrated demonstration projects

Target audience: Science funders, research community, practitioners, science policy makers

A network of long-term integrated studies is required in order to encourage experimentation with different approaches for analysing and building the capacity of regions to deal with environmental change and achieve sustainability. These studies must also address the human drivers and implications of environmental change in broad empirical contexts. The studies must pay attention to the challenges of including stakeholders in the entire research process. Learning to find a common language and joint problem framing must be evaluated and disseminated widely. The monitoring of these demonstration projects should enhance learning about how research can contribute effectively to sustainability transitions.

Good Practice Example:

The NCCR North-South

Location: Switzerland

Main actors involved: over 350 researchers in more than 40 countries worldwide

Time frame: started in 2001

Description: The NCCR North-South is one of 20 National Centres of Competence in Research (NCCRs) established by the Swiss National Science Foundation (SNSF) to promote scientific advancement in vital research areas. The centre is dedicated to finding sustainable, practicable solutions to specific challenges of global change. Central to all NCCR North-South activities is a commitment to partnership between institutions and individuals in the northern and southern hemispheres. Research is collaboratively conducted with a special emphasis on the needs of developing and transition countries, since they are arguably under the most pressure due to accelerated global processes of environmental, economic and sociopolitical change.

This example demonstrates the kind of long-term, implementation-oriented demonstration projects that are needed. Setting up such projects, developing new criteria for evaluating success, monitoring and learning from experience would be an important stepping stone in moving toward the RESCUE Vision.

More information: www.north-south.unibe.ch/content.php/page/id/265

Recommendation 4:

Develop sustainability education and learning that builds capacity for knowledge sharing and research across disciplines in an innovative open knowledge system

Target audience: Science and education policy makers, educators

Learning is the central element of an open knowledge society and essential for adapting to the complex and changing human condition in the Anthropocene. Processes are required that engage educators from pre-school through universities and far beyond, including a wide range of other professional areas, in a dialogue about the education and capacity building frameworks and institutions needed for an open knowledge and learning society. The new types of research needed to support sustainability transitions and processes of engagement need new skills and capacities that must be provided by the education system.

Good Practice Example:

Knowledge, Learning and Societal Change (KLSC) Project

Location: International Human Dimensions Programme on Global Environmental Change

Main actors involved: The project will create a collaborative community of people from the sciences, humanities and social practice, including participation in knowledge production by those living in key affected localities

Time frame: Draft Science Plan published in 2011

Description: The Knowledge, Learning and Societal Change (KLSC) project aims to better understand and explain the gap that currently exists between knowledge and action, so that steps can be taken to help societies move in more sustainable directions. Developing strategies for appropriate action requires greater insight into the drivers of global change and the behavioural transitions needed to avoid or respond effectively to possible effects. Understanding the complex mechanisms, dynamics and outcomes of the interplay between knowledge, learning and societal change will be crucial in guiding optimal policies and societal development toward a more sustainable global system. The implementation of the KLSC project will provide essential support to the implementation of the RESCUE Vision.

More information: www.klscproject.org

Recommendation 5:

Respond to the challenges and opportunities created by the internet for an open knowledge system ready for transitions towards sustainability

Target audience: Science policy makers, research and education community

The internet provides a means of access to knowledge, a repository of knowledge, a research tool and an agora that facilitates the production, diffusion and use of knowledge in responding to societal problems related to global environmental change. There is a need to discuss the role of the internet in an open knowledge society especially with regard to issues of credibility of knowledge. At the same time, there is a need to embrace the opportunities offered by the internet for creating networks or bringing them together.

Good Practice Example:

Climate of the Past review process

The open access journal *Climate of the Past* (CP) published by the European Geosciences Union (EGU) has an innovative two-stage publication process that involves a scientific discussion forum and exploits the full potential of the internet to:

- foster scientific discussion;
- enhance the effectiveness and transparency of scientific quality assurance;
- enable rapid publication;
- make scientific publications freely accessible.

In the first stage, papers that pass a rapid access review by one of the editors are immediately published on the *Climate of the Past Discussions* (CPD) website. They are then subject to Interactive Public Discussion, during which the referees' comments (anonymous or attributed), additional short comments by other members of the scientific community (attributed) and the authors' replies are also published in CPD. In the second stage, the peer-review process is completed and, if accepted, the final revised papers are published in CP. To ensure publication precedence for authors, and to provide a lasting record of scientific discussion, CPD and CP are both ISSN-registered, permanently archived and fully citable. This is one of many recent examples of using the internet for publication of research results. It demonstrates that some of the challenges posed by the internet, such as assuring authors' rights, can be dealt with.

More information: www.climate-of-the-past.net

Recommendation 6:

Create a dynamic, adaptive and integrated information and decision-support system on global change issues

Target audience: Science policy makers, science funders, research community

While numerous environmental, economic and societal information systems exist, the challenges of an unstable Earth and the development of an open knowledge society call for a dynamic information system that can be regularly and easily updated and that provides a forum for communication. The system would use indicators and markers for experts, decision makers and lay people to inform each other readily about the state of the social-environmental system, the likely short- to medium-term changes, the 'intervention' points and potential consequences of alternative choices.

Good Practice Example:

Peg – A community indicators system for the people of Winnipeg

Peg is a community indicator system (CIS) that has been developed for Winnipeg by the people of Winnipeg, led by a community-wide consortium of partners spearheaded by the International Institute for Sustainable Development and the United Way of Winnipeg. Peg's mission is to build the knowledge and capacity of the people of Winnipeg to work together to achieve and sustain the well-being of current and future generations.

To achieve its mission, Peg engages the citizens in an ongoing process that:

- measures, monitors and reports on indicators of well-being that reflect the values and aspirations of the people of Winnipeg;
- builds knowledge and informs community decisions and policy; and
- stimulates collaborative action to enhance community well-being.

Continuous improvement and up-to-date data will contribute to the agility and responsiveness of all citizens and Winnipeg as a whole.

This example demonstrates the design and use of an information system. The challenge now is to develop and run many more such systems in a coordinated but flexible way. The value of the system is that all societal actors can participate and thus learn about the state and trends of important features of the world that they live in but also about possible responses.

More information: www.iisd.org/measure/tools/indicators/winnipeg.asp

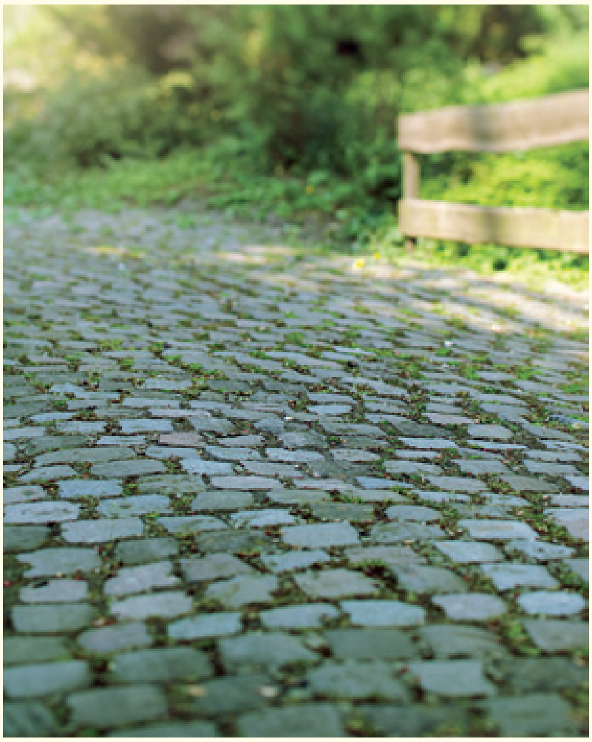
6. Conclusion

The challenges of an unstable Earth are complex and need urgent attention, if humanity is to avoid abrupt and disruptive changes to the life support system upon which it depends. The RESCUE initiative has looked at many aspects of the challenges and shows that the necessary response is not simply to produce more and more knowledge about the nature of the problems. In many cases there is enough knowledge on which to base decisions.

The proposal for an open knowledge system in which all societal actors, including the research community, engage in dialogues about the nature of the problems and their vision for the future, in which they test possible pathways to achieve that vision and learn from experience, requires new structures and processes in the knowledge system. Many of the elements of this vision can be found in niches, so the challenge here is to create the conditions under which good practice can spread. The challenge is also to build the capacity to do this.

Developing a vision is a normative exercise – the participants in the RESCUE initiative have described a world that would respond more effectively to the challenges of an unstable Earth. The next steps in the process are necessarily political. They would differ from steps often proposed in this kind of exercise, since they should call for **processes of change** that cannot be programmed in explicit steps with defined outcomes.

Overall, the RESCUE Vision will require dedicated and long-term funding for implementation-oriented, participatory research on the human-environment system. Other societal actors must be included into the process of funding decisions for this work. Robust evaluation criteria for science in an open knowledge system must be developed and implemented. A dedicated communication strategy is needed in order to secure large-scale public support for new approaches to problem-solving. In this way it will be possible to promote and support a diversity of mechanisms for engagement in knowledge production, learning and evaluation and link these to place-based needs and global sustainability concerns.



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Expanding the community of scholars and practitioners involved in this dialogue about how to deal with the challenges of global change is an important next step. The participants in the RESCUE initiative represent only a very small proportion of the people who should be involved.

Annexes

Annex 1. Composition of the RESCUE Task Force and Working Groups

RESCUE Scientific Steering Committee

Chair:
Professor Leen Hordijk (IT)
Vice-Chair:
Professor Gísli Pálsson (IS)

Together with the Chairs of the Working Groups

RESCUE Coordinator at ESF: Dr Bernard Avril

RESCUE Contact Person at COST:
Dr Carine Petit *(until spring 2011)*

RESCUE Task Force on 'Contributions from social sciences and humanities with regard to the challenges of the Anthropocene'

Chair:
Professor Gísli Pálsson (IS)
Members:
Dr Bernard Avril (FR)
Professor Carole Crumley (SE)
Dr Heide Hackmann (FR)
Professor Poul Holm (IE)
Dr John Ingram (UK)
Professor Alan Kirman (FR)
Dr John Marks (NL)
Professor Mercedes Pardo Buendía (ES)
Professor Sverker Sörlin (SE)
Professor Bronislaw Szerszynski (UK)
Dr Rifka Weehuizen (FR)

N.B.: Professor Joseph Alcamo (UNEP) was actively involved in this task force at the beginning of the RESCUE initiative.

Annex 1. Composition of the RESCUE Task Force and Working Groups

RESCUE Working Group on 'Collaboration between the natural, social and human sciences in global change studies'

Chair:
Professor Michael Goodsite (DK)

Vice-Chairs:
Professor Sierd Cloetingh (NL)
Professor Poul Holm (IE)

Members:
Professor Mauro Agnoletti (IT)
Dr Rachel A. Armstrong (UK)
Professor Frank Biermann (NL)
Professor Roy Gabrielsen (NO)
Professor Andrew Gouldson (UK)
Professor Milena Horvat (SI)
Professor Daniel J. Lang (DE)
Professor Rik Leemans (NL)
Professor Frank Maes (BE)
Professor Bedřich Moldan (CZ)
Professor Alice Newton (PT)
Professor Mercedes Pardo Buendía (ES)
Dr Bas Pedroli (NL)
Professor Walter Pohl (AT)
Dr François Roure (FR)
Professor Roland Scholz (CH)
Dr Andrew Sors (HU)
Dr Bernard Vanheusden (BE) (*WG Rapporteur*)
Dr Kathryn Yusoff (UK)
Mr Ruben Zondervan (DE)

RESCUE Working Group on 'Requirements for research methodologies and data'

Chair:
Professor Claudia Pahl-Wostl (DE)

Vice-Chair:
Professor Theo Toonen (NL)

Members:
Professor Claudia Binder (AT)
Dr Alex de Sherbinin (US)
Professor Carlo Giupponi (IT)
Dr Alex Haxeltine (UK)
Dr Christoph Külls (CH)
Professor Keith Richards (UK)
Professor Dale Rothman (US)
Dr Detlef Sprinz (DE)
Dr Caroline van Bers (NL)

Facilitator:
Dr Ilke Borowski-Maaser (DE)

RESCUE Working Group on 'Towards a 'revolution' in education and capacity building'

Chair:
Professor Karen O'Brien (NO)

Vice-Chair:
Professor Jonathan Reams (NO)

Members:
Dr Anne Caspari (IT)
Professor Andrew Dugmore (UK)
Dr Ioan Fazey (UK)
Ms Maryam Faghihimani (NO)
Dr Heide Hackmann (FR)
Dr David Manuel Navarrete (UK)
Dr John Marks (NL)
Professor Kari Raivio (FI)
Professor Patricia Romero-Lankao (US)
Dr Hassan Virji (US)
Professor Coleen Vogel (ZA)
Professor Verena Winiwarter (AT)

Foresight Consultant:
Dr Riel Miller (FR)

RESCUE Working Group on 'Interface between science and policy, communication and outreach'

Chair:
Dr Jill Jäger (AT)

Vice-Chair:
Professor Frans Berkhout (NL)

Members:
Dr Ilona Banaszak (SK)
Professor Ilan Chabay (SE)
Dr Sarah Cornell (UK)
Dr Bert de Wit (NL)
Professor Richard Langlais (SE)
Dr David Mills (UK)
Dr Peter Moll (DE)
Professor Arthur Petersen (NL)
Dr Christian Pohl (CH)
Dr Joan-David Tàbara (ES)
Professor Willemijn Tuinstra (NL)
Dr Lorrae van Kerkhoff (AU)

Annex 2. Membership of the Quality Reference Group

Chair:
Dr Marc Heppener (FR), ESF

Members and Deputy Members:
Professor Göran Collste (SE), COST, 2009-2010
Dr Ipek Erzi (TK), COST
Dr Afonso Ferreira (BE), COST, 2009-2010
Dr Mehmet C. Güran (TK), COST, 2010-2011
Dr Matthias Haury (BE), COST, 2010-2011
Dr John Ingram (UK), COST
Professor Alan G. Jones (IE), ESF, 2010-2011
Professor Maria Kaminska (PL), ESF
Dr Aslihan Kerç (TK), ESF
Professor Ulrike Landfester (CH), ESF
Professor Luisa Lima (PT), ESF
Dr Sonja Lojen (SI), ESF
Dr Patrick Monfray (FR), CNRS/ANR
Professor Ole J. Nielsen (DK), ESF
Professor Giuseppe Scarascia-Mugnozza (IT), COST
Professor Marko Tadić (HR), ESF
Dr John Williams (FR), COST, 2010-2011

Ex-Officio Members at ESF:
Dr Arja Kallio, LESC, 2009
Dr Paul Egerton, LESC, 2010-2011
Dr Nina Kancewicz-Hoffman, SCH and SCSS
Dr Jean-Claude Worms, PESC, 2011
Dr Bernard Avril, LESC
Dr Thibaut Lery, PESC
Dr Rifka Weehuizen, SCSS

Annex 3 **Definitions of types of research**

Source: RESCUE Collaboration
Based on personal communication from Professor Karl Georg Høyer, Oslo University College, on definitions in DEA (2008) as well as on further communication from the WG and the QRG. See also CoFIR *et al.* (2005); Bhaskar *et al.* (2010).

Monodisciplinary research is defined by and takes place within one discipline and within a dominating paradigm of that particular discipline. It is characterised by both ontological and epistemological homogeneity, but not necessarily methodological homogeneity. In **cross-disciplinary research** one discipline or its object is illuminated from the perspective of another. There is no requirement of either ontological or epistemological homogeneity. **Cross-disciplinarity** may take place between disciplines belonging to the same large group of science, e.g., social sciences. However, it may also cross boundaries between these groups, for instance, combining a discipline within social sciences with a discipline in humanities.

Problem-oriented research frequently involves a multitude of disciplines, and is characterised by ontological, epistemological and methodological heterogeneity. The most limited form is **multidisciplinary research**. In order to study an object that transcends disciplinary boundaries, this form of research draws on several disciplines without challenging the disciplinary boundaries and with the major part of research activities carried out within the traditions and paradigms of each discipline.

Interdisciplinary research shares the three forms of heterogeneity, but is based on an **integration** of a number of disciplines into a coherent research cluster providing a new framework for understanding and acting. The disciplinary interaction takes place in all phases in the research process; framing of research issues, execution of research, and the formulation and analyses of results. Interdisciplinary research tends to challenge both the disciplinary boundaries and the dominating paradigms within the several disciplines participating. Interdisciplinary research within popular divides such as the 'hard' or the 'soft' sciences is called moderate interdisciplinarity, whereas interdisciplinarity across the traditional divides is called radical interdisciplinarity.

Sometimes the adjective **integrative** is used instead of interdisciplinary as a synonym. However, integrative is also used to describe a form of science that is not just interdisciplinary but in addition bridges and brings together levels of analyses, cultural contexts of research and researchers, and various forms of knowledge and learning (including traditional, tacit, informal knowledge).

The concept of **transdisciplinarity** is used to imply inclusion of other forms of knowledge than scientific knowledge in the research process; in a **moderate form** with lay people taking part in the research process, or in a more **radical form** with lay knowledge given the same status and importance in research. This implies erasing the boundaries between science and society at large, also as regards to the knowledge produced. In this most **radical form** the concept of **post-disciplinarity** is applied. It must be noted that in **transdisciplinary science** there are **post-normal** and **normal** science conceptions. While **normal science** maintains the desire or aspiration of science to approximate truth, **post-normal science** (Funtowicz and Ravetz, 1990; 1991; and Turnpenny *et al.*, 2011 for a recent review in the field) dispenses with this aspiration given that inquiries may be dictated by urgency, high stakes and solutions required despite uncertainty. In such situations extended peer-review drawing on non-scientific stakeholders may become necessary.

Translational research denotes the value chain of research from conceptualisation, through empirical and archival work to generalisation and model building through to end-use and is usually supported by institutional support structures and funding models. While this form of funding and support is widespread in medical science it is not yet fully endorsed by global change research communities. In the theory of science literature, this concept is referred to as **transactional research** – which only partly relates to the long tradition of **action research**.

Annex 4. Approaches to Education in Relation to Environment and Sustainability

Primary Source: RESCUE Revolution

There are numerous approaches to education in relation to environmental change and sustainability. Ohman *et al.* (2005) reviewed the educational philosophy supporting environmental education (EE), ecological education (EcoE) and education for sustainable development (ESD). A more recent educational philosophy is education for a sustainable future (ESF). This spectrum of approaches to education and sustainability is discussed by Faghihimani (2011) and summarised below.

Environmental Education (EE), also called fact-based environmental education, developed during the 1960s and is based on an ontology that views humans as separate from nature. Nature is thus something that can be managed and controlled by humans, and environmental problems are attributed to resource exploitation and production processes in society. These problems are characterised as scientific and knowledge-based problems that can be solved by research, information gathering and action. Environmental issues are studied largely within natural science disciplines with factual information delivered from teachers to students, with the latter as passive recipients of knowledge. With its main concern being the quality of environment, EE has neglected social, economic and political aspects of environmental problems, and there has been little room for contributions from the social sciences and humanities.

Ecological Education (EcoE), sometimes considered normative environmental education, evolved during the 1980s, influenced by the eco-philosopher, Arne Naess. It represented a new orientation that included the social sciences and humanities in education about environmental challenges. In this approach, environmental problems reflect existing conflicts between society's desires and the laws of nature. Environmental problems are related to values, and thus can be solved by influencing people's worldview and attitudes. In contrast to EE tradition, this orientation considers humans as part of nature. The process of learning involves active participation of students in the development of knowledge, following on Freire's dialogical approach to education (Freire, 1972; 1995). EcoE focuses on environmental issues from a thematic perspective, and fails to integrate disciplines and provides little room for pluralistic and democratic perspectives.

Education for Sustainable Development (ESD), developed during the 1990s, assumes that humans and nature are bound in a cycle of events and tradition and the causes of environmental problems are conflicts between humans' wide range of achievement goals. These problems have been considered as political issues that should be dealt with democratically. In this respect, it is noteworthy that the United Nations Decade of Education for Sustainable Development (DESD, 2005-2014)[1], with UNESCO as the UN lead agency, aims to inclusively empower all people to take charge, cooperate and create a sustainable future. More specifically, the goal of ESD is to assist students in developing their ability to critically evaluate various alternative perspectives on ES. Students are engaged in an active and critical learning process and a broad range of learning materials is integrated. ESD has been considered the discourse that characterises modern environmentalism, reflecting the latest generation in the evolution of educational traditions related to the environment (Huckle, 1991; Hessleink, 2000). However, a lack of sufficient clarity about the philosophical umbrella in ESD approach, which comes from the pluralistic nature of the concept, has made it difficult to implement ESD in existing educational systems. For example, there are problems in integrating sustainability with educational theory, policy and practice.

Education for a Sustainable Future (ESF) is a more recent concept that developed at the beginning of the 21st century. This approach argues that it is not only development that needs to experience a paradigm shift to achieve sustainability, but also that paradigms of education have to fundamentally change (Blewitt and Cullingford, 2004). In contrast to ESD, ESF considers education to serve as a new way of looking at sustainable change and development, but sees a change in education as a prerequisite for sustainable development in human society. This includes lifelong and continuous learning, with a participatory learning process based on learning with peers. ESF proponents criticise the ESD tradition for being outer-directed and too instrumentally oriented. They insist on "considering the inner dimensions of valuative psychological and perceptual change" (Blewitt and Cullingford, 2004). The Sustainability Education in European Primary Schools (SEEPS) Project[2] is a recent example of what can be achieved for ESF.

Sustainability Learning is a concept recently developed (e.g., Scholz *et al.*, 2006; Hansmann, 2010; Tàbara *et al.*, 2005): "sustainability learning represents a much broader concept than sustainability education or education for sustainable development: Firstly, because learning processes aiming at sustainability are not confined to educational contexts; neither to formal nor to informal ones. Secondly, because mastering the challenges of sustainability depends on learning processes of individuals, as well as on learning processes of human systems at the level of groups, organizations, nations, supranational systems, and mankind as a whole"... "Consequently, sustainability learning is best understood as a multi-level concept that comprises individual learning as well as group, organizational, and societal learning."

This multi-level definition, which furthermore strongly emphasises the role of transdisciplinarity, was formulated by Scholz *et al.* (2006) as follows:
"Transdisciplinarity can be said to evolve from special types of problems, i.e., real, complex, socially relevant problems, which ask for the integration of the knowledge of science and society... Most of these problems are strongly related to sustainable development ... It can be said that planning and learning processes for sustainable development require transdisciplinarity as an approach ... This holds particularly true if the development and implementation of policies and mutual learning processes are targeted by the behaviour of individuals, industries, organizations, and governments. We refer to the corresponding process as 'sustainability learning'."

1. www.unesco.org/education/desd and www.desd.org.uk

2. www.education.ed.ac.uk/esf/index.html

Annex 5. **Glossary**

Words are marked with an asterisk (*) when they first appear in the main body of the report.

Agent-based modelling

Computational dynamical modelling of the actions, behaviours and interactions of autonomous agents (both individual and collective entities such as organisations or groups) with the aim of better understanding the functioning of a complex (adaptive) system as a whole. Such systems often self-organise themselves and create emergent order.

Anthropocene

The Anthropocene is the name of an emerging epoch in planetary history (Crutzen and Stoermer, 2000), a successor to the Holocene epoch, the last interglacial period. Most of the writings related to the Anthropocene suggest that it started in the late 18th century, when the rapidly growing combustion of fossil fuels began to change the composition of the atmosphere (Tickell, 2011; Steffen *et al.*, 2011). While there is no formal date for its beginning, Crutzen (2002) suggests that the Industrial Revolution of 250 years ago would be a logical one since this is the point in time that coincides with the first signals of increasing global concentrations of carbon dioxide and methane as measured in air trapped in polar ice. Since the start of this new epoch, the impact of human activity has begun to equal the measurable impact of geological forces, in speed and intensity, creating a completely novel situation that poses fundamentally new questions and requires new ways of thinking and acting (see Zalasiewicz *et al.*, 2010; 2011; for a review of the origin of the term).

Co-production of knowledge

Sustainable development requires production of knowledge that strikes a balance between scientific and other forms of knowledge. Therefore, increasing attention has been given to interactive ways of producing knowledge. The term 'co-production' refers to processes in which scientific and societal actors negotiate how different sources of knowledge can be brought together into new mutual understandings, e.g., see: www.envphil.ethz.ch/people/pohlc/papers/Pohl_et_al_2010.pdf

Decision makers and decision making

For sustainable development, decisions will have to be made by all societal actors. The 'Agenda 21', prepared for the 1992 UN Conference on Environment and Development, calls on countries to improve or restructure the decision making process so that consideration of socio-economic and environmental issues is fully integrated and a broader range of public participation is assured. Agenda 21 stresses the importance of integrated policy development, citizen participation in decision making, including full participation of women, institutional capacity building and global partnerships involving many stakeholders. For RESCUE, the terms 'decision maker' and 'decision making' relate to those public and private institutions which make decisions but also to all citizens, whose aggregated daily decisions ultimately influence the kind of world we live in now and will have in the future.

Earth system

The integrated system of physical, biological and ecological processes and interactions between the geosphere (lithosphere), atmosphere, hydrosphere and biosphere, in its past, current and future states. Earth system science provides a basis for understanding the world in which we live. Theoretically, a system is isolated from its environment, but this is an artificial construct. Earth is largely a closed system, meaning that it exchanges very little matter with its external outer-space, but the same is not true of the systems within the planet – geosphere, hydrosphere, atmosphere and biosphere – which interact to such a degree that they are virtually inseparable. Together these systems constitute a complex series of connections in which events in one sector exert a profound impact on conditions in another.

Global change

This is a generic term covering multiple and often interacting environmental changes and biophysical transformations of an interwoven system of human and natural processes. These include, in particular, climate change, and changing trends in biodiversity, land use, urbanisation, etc. They are intimately connected with processes of socio-economic and cultural globalisation. This transformation has undergone a great acceleration since the middle of the 20th century (Steffen *et al.*, 2004).

Governance

Governance describes the process of management and decision making for a given area of responsibility and the related implementation process. It includes the political, economic, administrative, social processes and institutions by which public authorities, communities and/or the private sector act. Different modes of governance include hierarchy (centralised/regulatory), market (competition) and networks (collaborative, participative), and these have an impact on which forms of knowledge occur in management and decision making processes. In the context of global change, for the governance of the transitions towards sustainability, increased attention should be paid to linked concepts of resilience, societal choice, acceptance and adaptation.

Institutions

Institutions are significant practices, relationships or organisations in a society or culture. Thus the term covers not only the 'organisations' but also the 'sets of rules, norms and procedures' that are used to organise society. These can be formal, written or codified, but also informal (unwritten), such as norms and conventions of society. Examples of formal institutions are the Constitution, the judiciary laws, the publicly organised market and property rights. Informal institutions are rules governed by social and behavioural norms of the society, family, community or unregulated business.

Interdisciplinarity

Interdisciplinary research and education combine two or more academic disciplines or fields of study, integrating their insights in pursuit of a common goal and to develop a greater understanding of a single subject, or solutions to a single problem that is too complex or wide-ranging to be dealt with using the knowledge and methodology of just one discipline.

Annex 5. Glossary

The combination involves finding a common language, new methods and questions. It allows the exchange of concepts, rules, methods and tools among different disciplines in order to achieve a global understanding of a common theme. In contrast, multidisciplinary research or education also involves two or more disciplines or fields of study around a common study theme and that examine simultaneously their respective objects but there is no attempt to find common ground between them or to share specific rules, methods and tools, while they combine their conclusions. [See Annex 3]

Knowledge

Knowledge refers to the way people understand the world, the way in which they interpret and apply meaning to their experiences. It relates to facts, information and skills acquired through experience or education, involving rejection, creation, selection, development and transformation of information emerging from complex and ongoing processes. Knowledge is inextricably linked to a social, environmental and institutional context.
Scientific knowledge: knowledge that has been legitimised and validated by a formalised process of data gathering, analysis and documentation and through peer review.
Explicit knowledge: knowledge that has been or can be articulated, codified, and stored and exchanged. The most common forms of explicit knowledge are manuals, documents, procedures, cultural artefacts and stories. Works of art can be seen as other forms of explicit knowledge where human skills, motives and knowledge are externalised.
Empirical knowledge: knowledge derived from and constituted solely within a restricted personal or cultural environment. Modern communication and information technologies, and scientific instrumentation, can extend the 'empirical environment' in which empirical knowledge is generated.
Local or indigenous knowledge: knowledge that is constituted and validated in a given environment, culture or society, developed within a local connection to the environment.
Traditional knowledge: Cumulative body of knowledge, practices and beliefs, evolving by adaptive processes and handed down by cultural, intergenerational transmission. It may not be indigenous or local, but it is distinguished by the way in which it is acquired and used, through the social process of learning and sharing knowledge.

Knowledge system

A knowledge system is defined as a network of actors connected by social relationships, formal or informal, that dynamically combine knowing, doing and learning to bring about specific actions for sustainable development (van Kerkhoff and Szlezák, 2010).

Learning

Learning is the acquisition of knowledge or skills through study, experience or being taught.
'Social (or collaborative) ***learning'*** refers to learning processes among a group of people who seek to improve a common situation and take action collectively. See, for example, www.ecologyandsociety.org/vol15/iss4/resp1.
'Sustainability learning' relates to learning to develop the capacity to manage options for the adaptation of human societies to the limits and changing conditions that are imposed by their own social-ecological systems. See, for example, www.ecologyandsociety.org/vol12/iss2/art3.

Open knowledge system

In an open knowledge system, knowledge is generated from multiple sources (some of which are scientific and evidenced-based) and shared at every stage of its development. Problems and solutions are defined by society as a whole, not just by researchers. An open knowledge system requires collective problem framing, societal agenda-setting and a corresponding institutional framework, extended peer review, broader and more complex but transparent metrics for research evaluation, better treatment of uncertainty and values, procedures to ensure that knowledge is 'placed in context', greater flexibility of research funding, cooperation of public and private organisations and stakeholder engagement. New media and new forms of public participation, combined with expanded access to information, will be crucial in building such an open knowledge system.

Reflexive process

Being reflexive requires that parties examine their priorities before they react. It is linked to the recognition that any framing of a system is partly constituted by the observer's perspectives and intended (re)actions. This involves asking "Why this situation is so important to me? Why do I care so much?" "What have I done to contribute to the problem?" and "What might be done in order to contribute to its resolution" (Rothman, 1997, p.37). The answers to these questions can be used to determine the priorities of participants, and help in the communication and resolution process.

Resilience

Resilience is the long-term capacity of a system to deal with change. It is either the amount of structural or functional change or disturbance that a system can undergo through short-term episodic shocks or perturbations without changing state or its essential functions; or the long-term ability of a system to recover from, to continue to develop, or to resist being affected by such change. It reflects the capacity of a system to stay or return in its original steady state. This definition emphasises conditions where instabilities can flip a system into another regime of behaviour, i.e., to another stability domain. It is also connected to knowledge-building and the building of learning capabilities in institutions and organisations.

Social-ecological system

An integrated system of people and nature with reciprocal feedback and interdependence. The concept emphasises the humans-in-nature perspective and that delineation between the social and ecological is artificial and arbitrary.

Sustainability

Sustainability refers to the capacity of the social-ecological system (see definition above) to be maintained at a certain rate or level. Overall, the term refers to the ability to maintain human well-being, social equity and environmental quality over indefinite periods of time, i.e., ensuring that future generations will have coupled human-environment systems capable of providing goods and services for the long run, without degradation in structure or function.

Annex 5. **Glossary**

Sustainable development

The Brundtland Commission coined what has become the most frequently quoted definition of sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs". See www.un-documents.net/wced-ocf.htm

Tipping points

Transitions where 'a small change can make a big difference' have been described as 'tipping points'. Beyond this point, rapid change can occur and it might even not be possible to return to the original state. There are many components (or sub-systems) of the Earth system that could display non-linear behaviour and transitions under human (anthropogenic) climate forcing. See researchpages.net/ESMG/people/tim-lenton/tipping-points/

Transdisciplinarity

Transdisciplinary research and education is a process of integration that overcomes disciplinary boundaries (even to stakeholders outside of science) for a more complete understanding of a complex world and that is oriented towards pragmatic issues affecting specific communities. It complements applied research and education in problem fields characterised by complexity and uncertainty: "There is a need for TR when knowledge about a societally relevant problem field is uncertain, when the concrete nature of problems is disputed, and when there is a great deal at stake for those concerned by problems and involved in dealing with them" (Pohl and Hirsch Hadorn, 2007). Participatory approach and collaboration between disciplines are the central elements of transdisciplinarity. [See Annex 3 and www.transdisciplinarity.ch/e/Transdisciplinarity/]

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