Introduction

Modern science is considered by many as one of the major drivers of the increase in human prosperity over the last three centuries (North, 2010; Mokyr, 2002). However, at the very moment that humanity fails to tackle major global crises of an economic, environmental and social nature, modern science seems incapable of providing operational solutions for overcoming these current crises. This failure of the project of modern science, as it was inherited from the enlightenment, has been analysed by many scholars in recent decades and gave a new impetus to the debate on the articulation between science and society (Arendt, 1958; Latour, 1993; Funtowicz and Ravetz, 1993). To improve upon this current state of affairs, researchers and practitioners have developed new path-breaking transformative approaches to science over the last twenty years. This book analyses the contribution of these approaches to managing the transition**[1] of human societies to strong sustainability**, with a particular focus on environmental and economic sciences.

Scholars and practitioners who gathered in May 2009 at a major conference organized by DG Research in Europe to discuss the meaning of sustainable development for science identified two major challenges for sustainability science (Jaeger and Tàbara, 2011; Jaeger, 2011). First, in dealing with sustainable development, there is a need for transformations in the core values and worldviews that drive individual actions and organizations. Science can contribute to such changes, but only if the challenges are addressed in a collaborative, iterative and exploratory mode. Indeed, sustainable development issues are complex and require ethical judgement on the limits of the earth's resources and responsible choices between multiple stakeholder perspectives. It is the responsibility of scientists to engage in new forms of collaboration with stakeholders and citizens, in the urgent search for and implementation of feasible options for effective transition to sustainable societies.

Second, there is a need to remove practical and institutional barriers for the development of the goal-seeking, iterative and integrative approaches needed to address the complex issues of sustainability (Jaeger, 2011, p. 201). This will require organizational changes, but also changes in the funding and evaluation of science. In particular, the funding and review

mechanisms for proposals and projects in sustainability science must be designed in ways that reflect the basic interdisciplinary features of the emerging field. In addition, long-term funding will be required for research on coupled social-ecological systems, which require a continued learning process with stakeholders in open-ended policy experiments. Finally, there is a need for institutional support for training and capacity building for scholars who wish to engage in sustainability science, as sustainability science requires a distinct set of professional competences – facilitation skills, systems thinking, ethical reasoning and abilities to build strategic partnerships, amongst others – that are not currently sufficiently encouraged in academic training programmes (Jaeger and Tàbara, 2011).

In response to these needs, visionary leaders in science policy administrations and higher education institutions have set up frontier science institutions for sustainability, both at the level of strategic research and training programmes and at the level of networks for broader capacity building. Well recognized examples that will be discussed in this book, which illustrate frontier research initiatives, are the programme at the Graduate School of Frontier Sciences at Tokyo University and the Institute for Landscape Ecology and Botany at the University of Greifswald. Both these institutions combine research into economics and ecology with a specific expertise in empirical social research and collaboration with social actors and practitioners. In addition, these institutes have set up interdisciplinary international master's programmes combining training in environmental sciences, economics and sustainability ethics. Prominent examples that illustrate networks for capacity building in sustainability science are the Swiss Network for Transdisciplinary Research (td-net) at the Swiss Academies of Arts and Sciences, and the Alliance for Global Sustainability between four science and technology universities in the US, Japan and Switzerland. Transdisciplinary research is key to all these capacity building initiatives and is understood as basic or applied research into socially relevant problems, implemented through research collaborations between scientific and social actors' knowledge and expertise. The goal of these networks is to advance the mutual learning between inter- and transdisciplinary researchers and lecturers across thematic fields, languages and countries.

Nevertheless, in spite of the wide recognition of the path-breaking contribution of these frontier science initiatives, the efforts of many sustainability science researchers and sustainability stakeholders are hampered in practice by the structural constraints imposed by the current mode of organization of the scientific research system. Indeed, as documented in this book, serious obstacles arise from the lack of career incentives in interdisciplinary and transdisciplinary sustainability science in

higher education institutions, the shortage of training opportunities in multi-method quantitative and qualitative case study research, and, most importantly, the dominance of mono-disciplinary peer review of research projects, individual researchers and of higher education institutions themselves. As shown in Chapter 5, the effects of the latter can be illustrated with a recent study that published bibliometric research of the peer-reviewed articles with the word "sustainability", either in the title or the keywords, in the approximately 16 500 peer reviewed journals of the Scopus database that were published between 1996 and 2009. This study showed that, even in the articles that explicitly mention sustainability as a keyword, cross-referencing between the three pillars of sustainability science (environmental, social and economic) is rare, especially for the articles in the environmental science journals, with only around 25 per cent of these sustainability articles citing other articles from the social science journals and 10 per cent from economics journals. For the articles on "sustainability" topics in economics journals, cross-referencing is more frequent, but the overall proportion of articles on sustainability in the economics journals is much lower and overall marginal.

The reality of these institutional constraints contrasts with the need of moving beyond the "value neutral" and "ivory tower" mode of organization of research for sustainability highlighted through the major failures of the current organization of research that will be discussed in this book. Nevertheless the conventional mode of research is deeply entrenched in the research practices in the core disciplines at the forefront of current sustainability research. To illustrate this, it suffices to analyse prominent economists' reactions to the 2008 financial crisis. These reactions, analysed in more depth in section 3.2.3 of the book, show two major strategies to keep mainstream economic analysis of the financial system within the remits of a highly abstract apparatus that is disconnected from empirical analysis of social and human behaviour. First, the recourse to abstract equilibrium or near-equilibrium modelling, in conjunction with the assumption of a uniform individual "representative agent", as the reference standard of sound science, leads to a systematic marginalization of the issue of systemic risks and instabilities in the financial system. A well-known example of this strategy is illustrated by the belief, originally shared by former Fed Chairman Alan Greenspan, that it suffices to introduce a sufficient number of appropriate derivative instruments to eliminate all uncertainty** from the market. This strategy supposes a uniform economic agent using ever more sophisticated tools to correct the mathematical uncertainties of the system. However, it is in stark contrast to real-world social dynamics, based on interactions between heterogeneous economic agents which have different information sources, motives, knowledge and capabilities. The second

strategy can be found in the beliefs expressly defended by prominent economic scholars (such as Robert Lucas, Nobel Prize laureate in Economics) that situations of crisis are outside the predictive power of economic sciences and cannot be dealt with scientifically within the discipline.

As shown through the analysis of successful contributions of economic research to sustainability in this book, what are needed instead for sustainability research are interdisciplinary practices combining economic research with analysis of social practices and an explicit discussion of the ethical orientations that underline the modelling options. For instance, research on ecosystem services in the Millennium Ecosystem Assessment has successfully promoted a set of tools based on a combination of market creation for sustainable use of ecosystem products, with the building of local community organizations and science-based decision support systems. A successful application of these tools which illustrates this embedding of analysis of market processes in broader social practices is the Rio Platano Biosphere Reserve in Honduras (Weaver, 2011). In this reserve, sustainability scientists have successfully supported communities to overcome the poverty-driven degradation of shared ecosystems, by reorienting the local economy towards non-timber forest products (such as cocoa, ornamental plants, medicines and oil), in the context of a community-based governance model. In a similar way, innovative modes of organization of research that combine descriptive–analytical** approaches of complex systems and the analysis of social practices have been proposed within post-Keynesian macroeconomics, ecological economics and Veblenian evolutionary economics. Because of the crucial role of economic thinking in policy making for sustainability, these approaches are analysed in depth in Chapter 3 of this book, with the view to providing concrete ideas for the transformation of the existing research practices.

The analysis in this book of the concrete practices and the scholarly literature on the mode of organization of sustainability science shows more generally the need to combine the descriptive–analytical approach of complex systems, developed for instance in economics and environmental sciences, with the analysis of and involvement in social practices and ethical debate. These requirements have been articulated in this book in terms of a set of three basic conditions that have to be considered together for successfully addressing sustainability problems through sustainability research:

- Interdisciplinarity**: first, sustainability science has to adopt an interdisciplinary perspective that combines the descriptive–analytical approach of complex socio-ecological systems** with the analysis of social practices and transition pathways.

- Explicit discussion of strong sustainability ethics: second, in so doing, sustainability science has to explicitly address how actors and decision makers in various problem situations can give concrete meaning to a strong sustainability ethics, which recognizes the intrinsic limits of the substitution of all natural life support systems by technological means or other forms of human-made capital. In particular, such discussions should clarify the situations in which a weak, intermediate or strong sustainability approach** is most relevant.
- Transdisciplinarity**: third, because of the context specificity of both the solutions and the socially relevant ethical options, sustainability science has to combine inputs from scientific and extra-scientific practitioners' expertise in organizing scientific research.

The general result from the analysis is the following: even though the experimentation with these conditions is still ongoing, there is a broad consensus amongst sustainability scholars and senior science officials that there is an urgent need to move from the purely descriptive–analytical approach of complex system analysis to a participatory and transdisciplinary science approach. As will be illustrated with concrete cases discussed throughout the book, the failure to integrate such a new approach to the organization of research can have dramatic consequences for solving concrete sustainability problems.

This proposition is building upon the large body of literature on transdisciplinary, community-based, interactive and participatory research approaches that has been generated in response to the major sustainability crises (Lang et al., 2012; Thompson Klein et al., 2001; Hirsch Hadorn et al., 2008). Although an open and still evolving concept, the key features of participatory and transdisciplinary research are a close articulation of scientific expertise and knowledge from the relevant social actors and practitioners throughout the research cycle and the linking of scientific problem framing with the societal problems from the very beginning (Jahn et al., 2012; Dedeurwaerdere, 2013). Accordingly, transdisciplinary researchers propose an "interface practice" between a societal practice of social problem solving and a scientific practice of interdisciplinary analysis.

The implementation of the three basic conditions imply an in-depth transformation of the current modes of organization of research. Nevertheless, both the existing current incentive and reward system of disciplinary research, and the existing mode of university/industry collaboration geared towards the needs of industry, remain important and well-established social benefits of modern higher education institutions. However, they are clearly insufficient for implementing the type of

multi-stakeholder collaborations required for solving complicated and interconnected sustainability issues. The aim of the envisioned approach therefore is not to build a substitute to already well-established institutions of modern science that have proven otherwise productive. Rather the goal should be to build a new layer of interdisciplinary and transdisciplinary research on top of the existing research infrastructure, in order to tackle the unprecedented sustainability crisis that humanity is facing today.

With the view to increase our understanding of the core principles of sustainability science and to better address both theoretical and organizational challenges of transdisciplinary modes of organization of scientific research, this book examines the following topics. Chapter 1 addresses the question of why sustainability science is needed and how emerging research programmes have attempted to address these needs, in spite of major institutional and practical hurdles. Based on this historical and institutional overview, Chapter 2 analyses the common features of sustainability science that emerge from existing practice. A crucial issue in this context is to analyse how sustainability science can contribute to implement the normative vision of sustainable development since its initial formulation in the Brundtland report 25 years ago. In addition, sustainability scientists also have to address new challenges that have grown in importance since the Brundtland report, such as the governance of technological transitions in the field of energy and sustainable food systems and the systemic risks generated by globalized financial markets. Chapters 3 and 4 review prominent sustainability science approaches that have been developed over the last two decades. These chapters highlight the failures of dominant "value neutral" and "ivory tower" modes of research in dealing with sustainability issues. To highlight the potential of an alternative, transdisciplinary mode of organization, these chapters focus more specifically on promising approaches in economics and environmental sciences, which have been developed to overcome the failures both of Walrasian general equilibrium* thinking in economics and purely biophysical approaches in environmental sciences. Because of their important influence on policy making, the greater part of the discussion is dedicated to the alternatives that have been developed to mono-disciplinary research in these two fields, but the discussion also points to developments in other fields to support the main argument. Chapter 5, finally, addresses the organizational and institutional challenges faced by universities and research policy officials when implementing the core organizing principles and methodologies of sustainability science elaborated in this book.

NOTE

1. Terms defined in the glossary are marked with a single or double asterisk upon their first appearance in the text.