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PERSPECTIVE

Science with Society in the Anthropocene

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Abstract Interdisciplinary scientific knowledge is necessary but not sufficient when it comes to addressing sustainable transformations, as science increasingly has to deal with normative and value-related issues. A systems perspective on coupled human–environmental systems (HES) helps to address the inherent complexities. Additionally, a thorough interaction between science and society (i.e., transdisciplinarity = TD) is necessary, as sustainable transitions are sometimes contested and can cause conflicts. In order to navigate complexities regarding the delicate interaction of scientific research with societal decisions these processes must proceed in a structured and functional way. We thus propose HES-based TD processes to provide a basis for reorganizing science in coming decades.

Keywords Transdisciplinarity · Human–environment systems · Science and society · Local–global scales

INTRODUCTION

Paul Crutzen proposes that the Anthropocene Age started with the industrial revolution, and that phenomena such as the ozone hole and climate change now demonstrate that the human species can be regarded as a geological factor modifying the earth system (Ruddiman 2003, 2007). This notion of the Anthropocene indicates fundamental challenges to mankind in general and to sciences in particular, as the interaction between human and social systems have to be addressed on all scales (Steffen et al. 2011).

Scientific knowledge from both the natural and social sciences is necessary but not sufficient when it comes to addressing complex human–environmental problems and fostering sustainable transformations of current systems (Westley et al. 2011). When dealing with sustainable transformations, science increasingly is and will continue to be involved in the challenge of dealing with normative and value-related issues such as social justice (Funtowicz and Ravetz 2001). This in particular is the case with problems that are socially contested and where value issues play an important role. Energy systems (e.g., what role might nuclear energy play?), food security (e.g., what role should genetically modified plants play?), or climate change (e.g., how should the uncertainties of climate change models be addressed? what are significant adaptation measures?) may serve as examples. In addition, science often does not have access to enough knowledge and power to sufficiently analyze the problem, as substantial knowledge lies in the hands of other societal actors such as private companies.

Intense discussion has centered on the question of how the academic system might adjust in order to be better prepared to effectively contribute to the coping of complex sustainability problems (Leshner 2002; Raven 2002; Rowe 2007). In the field of sustainability science, a consensus has emerged that academia needs to be reoriented in order to achieve a better balance between disciplinary and interdisciplinary research, and to actively involve stakeholders and decision makers at local to global levels in a *trans*disciplinary process (Gibbons 1999; McMichael et al. 2003; Martens et al. 2010; Reid et al. 2010a, b). The academic system is still fundamentally organized according to disciplines. As a response to the challenges mentioned, however, decisive changes in the academic system have already occurred. New hybrid disciplines such as “environmental sciences” have emerged, and integrated projects and integrated modeling are promoted. This also has implications for the education of students, who are increasingly involved in interdisciplinary settings to tackle (contested) human–environmental problems (Stauffacher et al. 2006; Barth et al. 2007; Wiek et al. 2011).

In this paper we present a novel process template for transdisciplinary processes based on a human–environment systems (HES) perspective. This functional-dynamic approach (Krütli et al. 2010b) can be valuable for sustainable transition projects as well as for constructive reviews of the state-of-the-art in integrated assessment modeling with stakeholders (Seidl and Le 2012). Thus, the focus of this contribution is on the process design of scientific investigations considering transdisciplinary dynamics. Readers should note that we consider a transdisciplinary process as a learning forum and not as a substitute for the decision process.

TACKLING COMPLEX SUSTAINABILITY PROBLEMS FROM A HUMAN–ENVIRONMENT SYSTEMS PERSPECTIVE IN A TRANSDISCIPLINARY PROCESS OF SCIENCE AND SOCIETY

We maintain that a thorough and continuous interaction between science and society is necessary, as sustainable transitions are based on scientific evidence as well as normative assumptions and therefore value laden. They go beyond the framework of a single scientific project and transcend traditional policy consultancy. Thus, they need to be linked to a broader multi-stakeholder discourse which makes relevant expertise, values, and interests from society accessible. To accomplish this, several approaches are offered[1] such as transdisciplinarity (TD). The approach was initiated by Jantsch (1970) and further promoted at a large-scale conference in 2000 with 500 researchers from academia and 300 people from outside academia (Thompson Klein et al. 2001). We follow the definition of this conference which focuses on processes of mutual learning between science and society, and which embodies the mission of science *with* rather than science *for* society. In its prototypical form, a transdisciplinary process is characterized by joint leadership on equal footing between representatives from the science community and legitimized decision makers. A transdisciplinary process should provide an arena that is not directly related to day-to-day politics, business competition, or academic daily routine. Rather, these processes aim to address Habermas' plea for undistorted communication that favors the "constraint-free force of the better argument" (Habermas 1984, p. 24). A portfolio of methods, such as formative scenario analysis, system analysis, or multi-criteria decision analysis contributes to the success of transdisciplinary processes, as evidenced by numerous case studies (Scholz and Tietje 2002; Mostashari and Sussman 2009). These studies on the sustainable transitions of organizational and political processes on local and regional scales (Scholz et al. 2006) show that TD is a valuable way to approach human–environmental problems and to participate in solving them in a socially robust manner (Nowotny 2003). This multi-methodological and multi-perspective approach can produce robust knowledge by explicitly addressing uncertainty issues such as uncertainty in data, models, and valuation. It also captures social learning (Cundill and Rodela 2012) and conceptualizes sustainability as ongoing inquiry and adaptive management.

Joint progress of science and society must proceed in a structured way, adapted to the task in the appropriate project phase (Stauffacher et al. 2008). This close interaction of scientific research with societal decision processes, however, is not free of intricacies, since research can be misused (Guston 2001); for example, already set policies can be legitimized (the politicization of science), or political decisions can be replaced by scientific analysis (the scientification of politics). We therefore clearly distinguish between different ongoing processes: the scientific research process, the legitimized (political) decision process, and the related public stakeholder discourse. TD is placed at the interface of these three, preparing subsequent democratic decision-making procedures. We identify different phases and steps of a prototypical transdisciplinary process (indicated by the circled numbers 1, 2, 3, and 4 in Fig. 1). If necessary, the steps can be iterated as the process progresses.

In line with several strands of the sustainability science community (Clark and Dickson 2003; Haberl et al. 2004; Folke 2006; Ostrom 2009), human and environmental (comprising natural and technical) systems in this approach are conceptualized as coupled and inextricably intertwined. Thus, a coupled HES perspective is needed to thoroughly examine and describe the structure, dynamics, and properties of systems and potential sustainable transitions (Gunderson and Holling 2002; Leshner 2002; Raven 2002; Liu et al. 2007a, b; Rowe 2007; Ostrom 2009). Since societal actors are often bound to diverse proximate issues, research questions based on societal input alone could be too narrow, focusing only on specific interests. The framework we use (Scholz 2011) identifies the essential structural components (e.g., hierarchies of human systems) and process relationships (e.g., feedback loops) between the subsystems of HES. In contrast to other systems, human systems allow, for instance, for specific social-epistemic operations such as reflection. Therefore the framework conceptualizes human and environmental systems as having different kinds of rationales. Importantly, the

[1] There are several other notions of science–society interaction, for instance action research, consultancy, and participatory research; for an overview cf. chapter 15 of Scholz (2011).

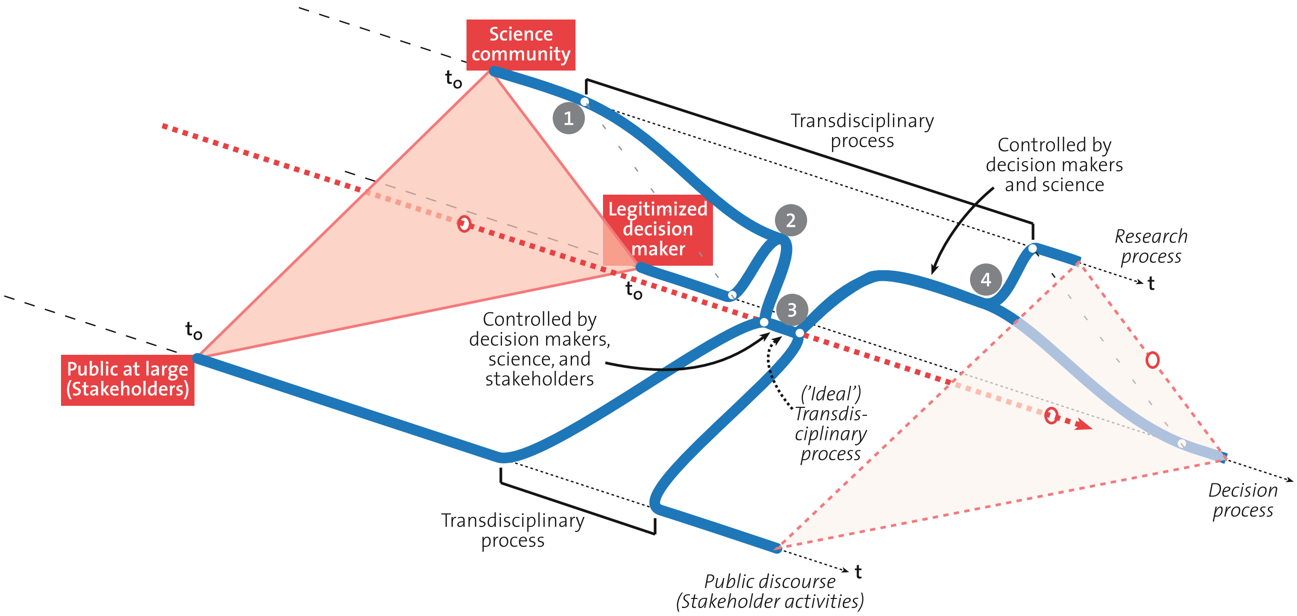

Fig. 1 A prototypical *Human–Environment Systems-based transdisciplinary process* according to our definition of transdisciplinarity; adapted from Fig. 15.1 in Scholz (2011). Three types of *key actors* (human systems), legitimized decision makers, science community, and public at large have different agendas and decision spaces (each represented by a corresponding *t* axis). The actors may leave their own decision space and join a pairwise (see ② and ④) or triple collaboration ③ on equal footing (see the *red dotted line*). The parties join because of common topical interests (but potentially conflicting views regarding realization) and form a kind of temporal institution to achieve legitimization via joint understanding and goals (for the institutional aspect, see also Hukkinen et al. 2006). Of course, one has to consider power issues, as some key stakeholders may have the structural and financial means to strongly influence the process. This holds, on the other hand, for academia, which has supremacy in terms of knowledge. These kinds of uncertainties cannot be eliminated but must be carefully monitored. In extreme cases a solution would be to terminate a transdisciplinary process. In a first phase ① the HES framework can be used to identify drivers and rationales of the *key actors* (e.g., individuals, companies, NGOs) based on the complementarity postulate (P1). The postulate *environment first* (P7) helps to identify the proper systems boundaries for the analysis and to define essential disciplines and scientific actors that should be included. The rationales and drivers of the key actors as well as their environmental awareness (P6) demand special analysis. Using the decision modeling postulate (P5), important societal actors can be identified that have to be included in the process, either because they are key decision makers or because they are affected by the consequences of these decisions. In the next phase, encounters between science and the identified legitimized decision makers ② usually lead to joint goal formation and problem definition. It should be added here that the process can be initiated either by scientists identifying an environmental problem or by a legitimized decision maker approaching science. Representatives from science and practice may differ in their environmental awareness (P6), and therefore perceive, for example, different kinds of problems at different hierarchical (human and/or environmental) levels. Besides consensus building (e.g., on the problem to be tackled), the core phase of a transdisciplinary process includes capacity building—for both decision maker and academia. In the next phase ③, the broader public becomes involved, e.g., in scenario workshops. Further, a system model is developed, linking particularly to postulate (P4) by identifying feedback loops between and among the systems. In the last phase ④ mutual learning between decision makers and science is confirmed and the parties return to their core business

environment of a human system also comprises other human systems as social environment and thus the *HES framework* allows for analyzing interactions and potential conflicts among human systems (Scholz 2011).

The Postulates P1 to P7 (shown in Table 1) constitute the *HES framework* and explicate the ontological and epistemological approach for dealing with HES. The framework can thus help to organize the relation of knowledge of scientific disciplines and society. It helps by identifying interfering rationales of human systems on an individual, company or societal level. At each project phase (numbers in gray circles in Fig. 1), the *HES framework* fulfills significant functions to conceptually structure the transdisciplinary process. We thus propose a HES-based transdisciplinary process. We describe the prototypical process in the caption of Fig. 1. In the text below, we make reference to one of more than 20 case studies carried out by us in transdisciplinary mode (see also column 4 of Table 1): the case study on the sustainable future of traditional industries in a small state of Switzerland, the canton Appenzell Ausserrhoden (*AR*), described in detail in chapter 18 of Scholz (2011) and in Scholz and Stauffacher (2007).

The scientific case study team of the *AR* case study involved undergraduate students in environmental sciences and researchers of ETH Zurich. The legitimized decision maker was represented by the president of the canton and members of various cantonal administration and agencies.

Table 1 The seven postulates (P1 to P7) constituting the *HES framework*

Number	Label	General description	Illustration by specific case on the sustainable transition of traditional industries
P1	Complementarity	Human and environmental systems are characterized by complementarity, mutually influencing and adapting to each other. Both systems are inextricably coupled	The activities of owners, managers, and workers of a firm constitute a company as an example of a human system at the organizational level. The company owns, utilizes, or affects parts of the material environment (e.g., production facilities, water, land, and products) and interacts on markets (i.e., by other human systems). The company itself is shaped by the market situation and the availability and quality of resources
P2	Hierarchy	Human and environmental systems both have hierarchical structures. In the case of humans there is a hierarchy of nested human systems ranging from the *individual* level through the *group*, *organizational*, *institutional* and *societal level* to the *supranational level* and the *human species*. Each of these levels has its own rationale and its own drivers. Both human and (natural and technical) environmental systems have different ontologies (here we restrict our considerations to the level of the individual)	Assigning all people involved in the study to their hierarchy level helped in understanding the influence they have and facilitated the definition of their roles
P3	Interference	There are disruptive and synergetic interactions among and within different levels of human and environmental systems (in particular between the ecosphere, ecosystem, and organism levels)	Potential conflicts emerge among firms and among hierarchy levels (e.g., national agencies/institutions)
P4	Feedback	There are different types of feedback loops within and between human and environmental systems. Primary feedback loops are formally expressed by the environmental response to actions within the human system that occurs after a certain (relatively short) time span. Secondary feedback loops include possibly unintended, often delayed, feedbacks caused by an action	In the *AR* case study, university, firms, and the canton (state) extended their knowledge as they learned how to anticipate and better cope with feedback loops in human and environmental systems. This learning process was induced by the whole *AR* case study
P5	Decision	Human systems (but also other organismic systems) can be conceived as decision makers that have drivers and act to satisfy goals by applying strategies and utility functions	Individual firms (human systems) can choose between different options for collaboration (strategies), which are differently preferred by various key decision makers (human systems)
P6	Awareness	Human systems have different types or degrees of environmental awareness (deployed during all phases of a decision process)	Other firms are often perceived only as competitors (restricted awareness of the social environment). The potential market benefits of collaboration are not explicitly perceived and assessed
P7	Environment first	The effective analysis of inextricably coupled human and environmental systems, as well as the planning for sustainable human–environment interactions should be based on a thorough analysis of the material and social environment and its respective rationales	Traditional industries (such as sawmills) must be aware of the natural resources as well of the market situation (e.g., is there enough demand for products?)

The right column illustrates how scientists used the postulates to structure a transdisciplinary case study in Switzerland in interaction with societal actors; see Scholz and Stauffacher (2007) and main text

Regarding phase ①, it was recognized, referring to system complementarity (P1), that companies in *AR* produce and sell products in a specific environmental setting and network of actors (market), for instance, impacting the material environment by emissions and being influenced by their social environment, i.e., competitors and collaborators along the supply chain. The essential natural and social science disciplines that analyzed the environment (P7) and related actors were, among many others (economic) geography, industrial and regional economics, business and management sciences, industrial ecology, environmental sciences, and regional and economic development planning. Both the cantonal government and different traditional industries—sawmill, dairy, and textile—were identified as key stakeholders and the broader public as affected (P5). During phase ②, the administrative head of the canton contacted the ETH professor, and co-leadership between them was established. Further contacts with the different administrative departments of the canton, CEOs of the named industries, and a steering group with half its members from science and half from the region were established. How a company perceives its environment may influence its decisions (P6). Additionally, different perceptions among the actors have to be explicitly addressed in a joint effort to define the problem and potential transition steps. First "experiential case encounters" took place by conducting a media analysis, and in-depth interviews with key people from the region to inform the problem definition. The focus of the study comprising the system boundaries and several methodological steps were agreed on by the steering group, and the guiding question was defined. The steering group also monitored the quality of the process and evaluated the project work. In phase ③, for the different working groups (one for each branch of industry), "reference groups" were initiated, comprising a range of different people such as farmers, teachers, planners, and a pastor. The history and dynamics of each industry branch was investigated by document analysis and statistical data analysis. Additionally, structured interviews with the owners or CEOs of local companies were conducted to address (even confidential) economic data or environmental issue such as energy use. A scenario analysis produced potential scenarios for the further (sustainable) development of the three branches, which were evaluated by means of two multi-attribute utility approaches. The first focused on data-based performance of the respective scenarios, whereas the second comprised an intuitive (holistic) overall assessment of the scenarios by stakeholders. Results of the two approaches were compared and jointly discussed in order to, finally, derive robust orientations for the decision makers. A classical case of interference (P3) between hierarchy levels became visible during the process: the promoter of economic development for the canton perceived the canton as modern and supported modern industries such as information technology and biotechnology. Other, more traditional, branches were largely neglected. It turned out, however, that other actors rated the value of traditional industries for this canton as considerable. This indicates the substantial mutual learning that took place before the project phased out in phase ④, and both decision makers and scientists again focused on their core business. After the project ended several activities still took place on different levels. The project was evaluated in terms of its societal effects (Walter et al. 2007); a scientific article was published that describes the project in detail (Scholz and Stauffacher 2007); the results directly entered administrative and political processes in the region and several endeavors were initiated that were heavily influenced by the project (for instance, the establishment of a district heating system fuelled with wood chips and pellets from local forest or the cheese dairy processing local milk).

OUTLOOK: THE HIERARCHY OF PROBLEM AND SOLUTION

HES-based transdisciplinary processes define a new role for science and scientists (as well as decision makers and stakeholders) that needs careful reflection. To tackle the immense sustainability problems on regional and global levels, scientists increasingly no longer "only" analyze these problems, but rather relate themselves to a societal transition process (Wiek et al. 2012). Scientists are neither working as consultants nor taking the traditional role of "speaking truth to power". A transdisciplinary process requires that all participants contribute in a mutual learning process on equal footing. Transdisciplinary processes thus demand certain constraints and a discourse culture. Various case studies on decision processes for nuclear waste disposal have shown that this is possible even for highly contested issues (Krütli et al. 2010a). This ability also has to be developed within academic education. Student education must include encounters with ill-defined human–environmental problems and interaction with key actors from practice. The AR case study illustrates in brief what such a transdisciplinary process might look like. As a research-based teaching course, the case study has both contributed to the education of students as well as enabled crucial societal decisions. Many decisions on a cantonal level (e.g., changing forestry law to secure the sawmill industry), company level (e.g., business strategies of textile industry), or collaborative level (e.g., joint wastewater treatment plants of municipalities and industry) were motivated and legitimized by the case study. The case study presented serves as a prototypical procedure for acting locally, but, if organized in a coordinated manner, also has the potential of achieving impact on a higher scale. This is important, since—given the notion of the Anthropocene—socially robust solutions for the human–environmental problems addressed are needed globally.

Global coordination for local and regional case studies that follow the transdisciplinary mode is necessary to achieve global impact. This coordination might itself be organized in a transdisciplinary way. A current example of implementing this up-scaled transdisciplinary approach is a project dealing with the sustainable management of the global phosphorus cycle GlobalTraPs, see Scholz et al. (in preparation), which establishes global and local transdisciplinary processes using a HES perspective. By relating the knowledge of science and practice to all hierarchy levels HES-based transdisciplinary processes provide a basis for reorganizing science in coming decades. One might not regard the process portrayed as a completely new form of science. However, a joint problem definition at the beginning of a project is rather unusual in today's scientific world. Additionally, it is not just about using different epistemics but creating new ones by relating and combining scientific with practical knowledge and the values of people. This kind of knowledge emergence might "not be locatable on the disciplinary map", that is it cannot be traced back who exactly contributed what (Gibbons et al. 1994, p. 168). The process described may result in novel research questions, break up scientific boundaries and change the logic of disciplines to follow their peer-related laws of identifying research questions and gaps. Thus both a new epistemic level can be reached and societally relevant and robust orientations can be formed.

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