Sustain Sci (2015) 10:653–671
DOI 10.1007/s11625-015-0327-3

The real type and ideal type of transdisciplinary processes: part II—what constraints and obstacles do we meet in practice?

Roland W. Scholz[1,2] · Gerald Steiner[3,4]

Received: 11 March 2015 / Accepted: 12 July 2015 / Published online: 22 August 2015

Abstract This paper builds on the theoretical foundation outlined in Part I ('The real type and ideal type of transdisciplinary processes: part I—theoretical foundations') which is included in the same special feature. Mode 2 transdisciplinarity processes are characterized as processes that relate or integrate problem-oriented interdisciplinary research with knowledge generated in a multi-stakeholder approach with the objective to develop socially robust orientations, for instance, on sustainable transitioning. In practice, transdisciplinary processes may have different functions (i.e., societal capacity building, consensus building, analytic mediation, and legitimization). Practitioners and scientists may follow different interests. And we may distinguish between different types of knowledge integration (including different perspectives, modes of thoughts or cultures). Thus, the reality of transdisciplinarity processes may become a very complex and ambitious venture whose multiple objectives are difficult to realize in practice. This paper reviews the existing challenges, obstacles, and constraints of transdisciplinary processes. This review refers to 41 mid- and large-scale transdisciplinary studies run by members of the ITdNet at seven universities on sustainable transitions of urban and regional systems, organizations, and policy processes. A comprehensive table can be used as a checklist for identifying and coping with constraints and obstacles of transdisciplinary processes in practice. The discussion identifies the main challenges for the future development of transdisciplinarity's theory and practice, including linking Mode 1 transdisciplinarity (i.e., the relating of disciplinary causation for which no interdisciplinarity is possible by merging concepts and methods) and Mode 2 transdisciplinarity, which targets sustainable knowledge and action for system transitioning.

Keywords Transdisciplinarity · Knowledge integration · Sustainability learning · Mode 1 transdisciplinarity · Mode 2 transdisciplinarity

Handled by Osamu Saito, UNU-Institute for the Advanced Study of Sustainability (IAS), Japan.

Electronic supplementary material The online version of this article (doi:10.1007/s11625-015-0327-3) contains supplementary material, which is available to authorized users.

✉ Roland W. Scholz
roland.scholz@igb-extern.fraunhofer.de

[1] Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB), Stuttgart, Germany

[2] Department of Psychology, University of Zurich, Zurich, Switzerland

[3] Department for Knowledge and Communication Management, Danube University Krems, Krems, Austria

[4] Weatherhead Center for International Affairs (WCFIA), Harvard University, Cambridge, MA, USA

Towards a practice of high-quality transdisciplinary processes

Transdisciplinarity has found its way increasingly into recent academic literature. However, as we pointed out in both papers on 'The real type and ideal type of transdisciplinary processes' (Part I on the theoretical foundation and Part II on its real-world implications), transdisciplinarity is in danger of becoming used increasingly in an inflationary manner for labeling any interaction taking place between scientists and practitioners, including consultancy, participatory research, and even interviews with practitioners. Thus, transdisciplinarity is in danger of losing its strength as a powerful approach and as a third mode (supplementing disciplinarity and interdisciplinarity) of doing and utilizing science for dealing with the challenging and complex real-world problems that society faces today (Zscheischler and Rogga 2015). Future transdisciplinarity research will depend on a clear orientation and differentiation in relation to other collaborative approaches, such as a mere multi-stakeholder discourse or the Triple Helix approach. Naturally, both the Triple Helix model as well as the inclusion of science in multi-stakeholder discourses help to extend the knowledge basis compared to purely disciplinary approaches. However, the Triple Helix approach neither sufficiently takes into account the potential and the specifics of the mutual learning process and knowledge integration between science and practice as they occur in transdisciplinarity.

As introduced in Part I (Scholz and Steiner 2015; Fig. 1), transdisciplinary processes distinguish between (a) problem-oriented interdisciplinary research, (b) a multi-stakeholder discourse, and (c) the process of facilitation. Part II of the paper provides insight into constraints and obstacles that have to be managed if someone wants to participate in, facilitate, or initiate a transdisciplinary process. The discussion deals with fundamental questions such as the added value of transdisciplinarity for science and practice, the challenge of evaluating transdisciplinary processes, the role-conflicts faced by participants, and several theories of science questions that are involved in Mode II transdisciplinarity.

Mutual learning between science and society (which also includes policy makers and politicians as well as other societal stakeholder groups) is considered the core of transdisciplinarity. Transdisciplinarity acknowledges that science and practice refer to different epistemics (i.e., ways of knowing) and reference systems. Different reference systems may include different modes of validation, i.e., what is considered as good, adequate, or false. The reference or objective of *science* is to develop consistent and coherent theories and knowledge for better understanding the complex processes of reality. Here, one may find certain scientific, methodological, or disciplinary standards. By contrast, stakeholders (practitioners) serve certain—partly conflicting—personal or institutional interests, roles, and societal functions. The reference system is the success that ideas or actions have in practice from the very perspective of a specific stakeholder group. The primary objective of a company is to make a profit and to survive on the market. Non-governmental organizations follow a wide range of specific goals, norms, and interests, and a main criterion for success is in what way they may attract others to share and support these objectives and interests of certain actors or the building of societal norms.

This is the starting point. One of the key prerequisites for initiating a successful transdisciplinary process is to negotiate and define a proper goal or guiding question, the process of answering in itself provides benefits to all participating stakeholder groups. However, scientists must also acknowledge that participation allows for better understanding of complex issues or the development of methods that may contribute to the scientific body of knowledge (as a primary self-interest of scientists). Part I of this paper presented different functions (i.e., societal capacity building, consensus building, analytic mediation, and legitimization), the main outcome (i.e., socially robust orientations for sustainable transitioning), methods, and organizational aspects (such as establishing co-leadership of practitioners and scientists on all levels of a project) of transdisciplinary processes. This part discusses and demonstrates—when referring to a 22-year process of running transdisciplinary studies—under what constraints sustainability learning in transdisciplinary processes may become reality.

After presenting the reference set of studies, we will identify obstacles of and barriers to a transdisciplinary process that may be encountered and that must be addressed and managed within the context or in the initiation, preparation, core, and post-processing phases of a transdisciplinary process. When thinking through key elements and obstacles that can be experienced in the reality of a transdisciplinary process, the reader may also better understand the balance of high-quality scientific performance on a broad scale and the need for methods as well as for certain methodological issues necessary for a successful transdisciplinary process (see, e.g., Vilsmaier et al. 2015). In addition, the fundamentally different roles that science and scientists take compared to more common procedures such as applied research or models of theory–practice interaction (e.g., the Triple Helix approach) will become more easily understood. The discussion focuses on critical questions, such as the added value of the theory and the practice of transdisciplinarity compared to other models of science–practice cooperation, the challenge of evaluating transdisciplinary processes, the role-conflicts that participants may face, or the question of what conception and role of science (e.g., normal vs. post-normal science) is appropriate. The paper ends with seven propositions about transdisciplinarity as an emerging research methodology that, among others, identify deficiencies and priorities for future research.

To what practice do we refer?

In the following, we focus on the Zurich 2000 conception as a specific ideal type of transdisciplinary processes (see Scholz and Steiner 2015, Box: Mode 2 Transdisciplinarity in a nutshell). Here, science and practice collaborate on equal footing which in its ideal is established by co-leadership between science and practice. A transdisciplinary processes includes and relates (i) an interdisciplinary process for better understanding the mechanisms, barriers, options, knowledge gaps, etc., of a specific case of sustainable transitioning; (ii) a multi-stakeholder discourse including representatives of all key stakeholder groups, in which the (iii) facilitation of this process is a special challenge. A specific characteristic is that science remains independent. Practitioners benefit from science such as scientist may gain insights into complex real-word structures by mutual learning. From a science perspective, this may stimulate the development of new methods, theories or new subject-related issues (e.g., what makes sustainable traffic). Our reference set comprises 41 transdisciplinary studies of the International Transdisciplinarity Network (ITdNet 2014, see Supplementary Information I). These studies were conducted on the sustainable transition of urban, rural, or resource systems, companies, and policy processes, and the authors initiated or co-led 23 of them. Most of these studies were embedded in master curricula courses of environmental or sustainability sciences, human ecology, geography, or interdisciplinary curricula of seven European universities (Steiner and Posch 2006) and the University of Stellenbosch, South Africa. All studies linked an interdisciplinary science team and a multi-stakeholder discourse. Thirteen studies operationalized co-leadership (i.e., a legitimized decision-maker who participated and took joint responsibility for the "socially robust orientations"). In seven cases, a formal agreement took place after the initiation phase. All studies included the (legitimized) decision-makers as primary practice partners and stewards of the study (see Fig. 2).

If the reader wants to look at "prototypical cases", i.e., studies which are closest to the ideal type, the Swiss Appenzell studies on landscape transitioning (Scholz et al. 2006, 2002; Stauffacher et al. 2008) and on the future of traditional industries (Scholz and Stauffacher 2007; Scholz et al. 2003) or the Austrian Eisenerz study on the future of an abandoned iron-mining region (Posch et al. 2005; Steiner and Posch 2006) may serve as examples. These are used as main references. Table 1 includes the main characteristics of all 41 studies, supplemented with features we consider to be essential.

The studies represent mid- and large-scale formats, including approximately 6–30 scientists and 10–300 practitioners. According to a pragmatic, rule-of-thumb classification, a stakeholder classified as a study participant has to take part in the process for at least three meetings and spend a full day (8 h) on activities related to a transdisciplinary process. Spending such an amount of time usually indicates that the stakeholder shows some basic commitment.

Some transdisciplinary studies were also conducted on small-scale projects such as a master thesis (Aronsson 2002; Günther 2004) or parts of a PhD thesis. We should note also that private research institutes such as the Institute of 'Sozialökologische Studien', Germany, have contributed to the theoretical development of transdisciplinarity (Jahn et al. 2012) and are facilitating transdisciplinary projects. This may reflect that transdisciplinary studies deal with boundary issues and that the facilitation of transdisciplinarity (see Fig. 1) may become professionalized.

What obstacles do we encounter at which stages of a transdisciplinary process?

The review and discussion of obstacles, challenges, and constraints refers to (C) the context and to the (1) initiation, (2) preparation (3) core phase, and (4) post-processing phase (see Table 1).

Context

When facing a complex, societally relevant problem that may provide a potential starting point for a transdisciplinary process, the first critical question is *whether the situation or case is suitable for a transdisciplinary process*. If we exclude states of war and rapid emergency management, the first question is whether the context endorses a successful transdisciplinary process. Transdisciplinarity is closely bound to the conceptions of modern, liberal communication and role model (Habermas 1996) that underlie Western democracy. This communication includes not only an open interdisciplinary discourse but also, in general, questions of values, morality, jurisprudence, economic rules, etc. Thus, the cultural and political system (see C1.1 in Table 1) and the discourse structure (C1.2) constrain the transdisciplinary process. For instance, a transdisciplinary process in China failed because the Chinese stakeholders obviously could not participate in a process in which a critical picture of a wastewater management system and a bottom-up, stakeholder-driven process would have resulted (Huang et al. 2007). Furthermore, there are settings such as emerging formal settlements of cities in developing countries where there are no legitimate decision-makers for residents (van Breda et al. in press) or where criminal (drug) clusters prevent dialogues by arguments.

The roles that scientists and practitioners are taking (C1.3), self-perception, and expectations of others are important issues. For instance, the common model for a natural scientist is not to promote a discourse culture. This may be illustrated by the phrase "we should stop talking and start working", which has been repeatedly expressed by natural science students and researchers who expected a clear task and problem definition and were not used to defining objectives through discussions.

A very important aspect is to analyze, evaluate, and finally decide whether a real transdisciplinary process and a

Table 1 Obstacles within the transdisciplinary process

C Context/general		
Phase	Issue	Obstacles
C1 Societal preparedness for a transdisciplinary discourse	*C1.1 Cultural conservatism* Preparedness of a society and a political system to accept the risk of a change	Does society allow to change social rules (farming practices, gender interaction, etc.)
	C1.2 Discursiveness/societal structure and its stratification Does the society appreciate/allow for an open discourse with various stakeholder groups?	Non-democratic, totalitarian structure, arguments are primarily valued according to the position of the sender
	C1.3 Role models Are the roles between scientists and practitioners differentiated? Are scientists/participants allowed to make commitment to have limited knowledge? May participants switch from positions to interests? (Fisher and Ury 1981)	Scientists are considered as omnipotent; scientists (primarily) follow their personal political value system and/or want to become decision-makers; practitioners ("local researchers") are considered as scientists
	C1.4 Protected discourse arena Is the discourse arena considered as a protected arena which promotes learning/thinking; is the rule "all information is handled in a way that it may not be assigned to a single person" guaranteed and believed by the participants? What is the consequence of deviant behavior?	The project leaders are not credited to be trustworthy (to guarantee the protected discourse arena). Participants may just misuse the participation to get better information about others (sit in and listen). No trust-building methods (small-group meetings, in-depth interviews, game-like personal encounters) are applied
	C1.5 Cooperative learning and motivation Balance between consensual and competitive; accepting the otherness of the other (gender, ethnic group, religion, age, language, etc.)	African, Asian, and European farmers have differently formed cooperative motivation and forms of learning; aggressive yellow press or 'destructive agents' may harm the building of motivation
	C1.6 Self-perception and expectations The stakeholders' self-perception (what is my role in a transdisciplinary process, what may/should I provide, what may the others provide, in what way may the system change) has to be compatible with the requirements of a transdisciplinary process	Inconsistencies in expectations regarding underlying problems as well as objectives and overall vision are unavoidable, but can be dealt with if they are made visible
	C1.7 Reflexivity Acknowledging the domain-specific superiority of different types of epistemics	One type of reasoning/causation (analytic or intuitive, experiment vs. survey, etc.) is considered to be superior for all activities
	C1.8 Institutional support Does the transdisciplinary process receive sufficient institutional support from the science side and organizations of the key stakeholders?	The benefits of transdisciplinarity have to be understood by universities and science organizations and the leaders of public agencies and organizations, industry, etc., as well as from practice organizations; the image of transdisciplinarity (being "trans") may harm
	C1.9 Non-(day-to-day) politicized discourse Though transdisciplinary discourses may deal with politically highly contested issues (and day-to-day issues), the participants are asked not to deal with arguments from the day-to-day political agenda	No (explicit) rules are found which prevent that the discourse gets stuck to mere antagonistic ('position-based') reasoning. No method to transfer "non-go" issues to semi-abstracted representations of an issue are found
	C1.10 Pre-competitive issues If economic issues are addressed only dialogues that deal with early stages of development are possible	Do not focus on technological but rather on legal framing and social prerequisites of technology innovations
1. Initiation		
1.1 Initial idea	1.1.1 *Choice of system and topic* Does the goal of the scientists/practitioners who pop up with an idea necessarily ask for (the high) investment of a transdisciplinary project/process? For scientists: is a new scientific new issue dealt with? Is the scientific innovation defined?	The project is dealing with a no-problem problem. The selected case/the problem is not sufficiently ill-defined to justify the expenses of a transdisciplinary process for some key stakeholders

Table 1 continued

C Context/general		
Phase	Issue	Obstacles
1.2 Building partnership	1.2.1 *Co-leadership* Leadership, responsibilities. Is the legitimized decision-maker willing to take co-leadership?	The issue/topic is overly contested/politically contaminated. Scientists and practitioners do not acknowledge different value systems (even if they are compatible with human rights and national constitution); the co-leaders from practice are not formally legitimized or not informally accepted by all stakeholders
	1.2.2 Added value Clarify the benefits for all participating stakeholders. Clarify what new knowledge with respect to the topic, methods, or transdisciplinarity the project wants to generate	No tangible incentives for practitioners and for scientists are provided. Scientists and practitioners have to define and to communicate their interests and desired outcomes
	1.2.3 Accepting the otherness of the other Are the differences in culture (incl. religion), history, and interests of the scientists and of the different stakeholders explicated and accepted by the participants? Scientists have to write papers, practitioners have problems	Practitioners do not sufficiently acknowledge the research process (e.g., by providing data for science purposes). Scientists or not willing to fully collaborate with key stakeholders who have diverging political, commercial, and personal interests
	1.2.4 Including unconventional thinkers Including forerunners and out-of-the-box thinkers is important to successfully cope with ill-defined problems	Unconventional thinkers are considered as nutcases who destruct discourses; no proper processes are found to include these people/groups/organizations
	1.2.5 Rules for emergency/exit scenarios In case of conflict, usually the project leaders are responsible for mitigation	No rules and scenarios for a potential pre-exit are discussed (i.e., for ending a project before its presumed date of completion)
	1.2.6 Contract on rights, responsibility, and data Scientists normally get access to sensitive personal, institutional data that only should be conveyed to few, trustworthy people. What are the rules for utilizing data or findings on contested issues in and after the project?	The key participants (at least the co-leaders from science and practice) should sign a contract including the guiding question, the responsibilities, break-off rules, access to data, and utility- and property rights
2. Preparation		
2.1 Problem definition	*2.1.1 Joint system/problem discovery* Guarantee that the scientists know the real-world system sufficiently well. Induce experiential case encounter	A direct "system encounter" is abandoned as the study team supposed that they know "how an issue functions". No methods such as Experiential Case Encounter (Scholz and Tietje 2002) are applied; scientists do not experience the 'real' problems; no creative thinking is prepared
	2.1.2 Guiding question Does the process of joint problem definition allow to ratify a consented guiding question which represents the interests of science and practice in a balanced way?	The guiding question is not well thought through, consented, agreed upon, and thus gets lost or shifts in the course of the transdisciplinary process
	2.1.3 Faceting the case/problem (i.e., structuring) The complex system has to be embedded in a proper "conceptual grid" which allows investigations that provide satisfying answers to a guiding question	The faceting (building of subprojects) is insufficient; no detailed causation (explanation, see Fig. 4) becomes possible; the faceting is too specialized and is insufficient for a synthesis with respect to the guiding question
	2.1.4 System boundaries Are the system boundaries (physically and conceptually) appropriate for the guiding question?	Important aspects, parts of the system are not included; the temporal, physical, and social layers of the system are not well defined
	2.1.5 System model The study and guiding question should be based on a joint system model which is shared by scientists and practitioners. The system model may serve for the organization of the process see (2.3)	No (cognitively) salient models (such as supply–demand chains, material flow charts, system dynamics models/mind maps, up to deep pictures, and storyboards (incl. persons)
	2.1.6 Communication/shared language In order to avoid misunderstandings within the discourse process a common/shared language is needed; this concerns not only the communication between scientists and stakeholders, but also between different disciplines	Domain-specific language and scientific terminology may be counterproductive for developing a shared understanding of a complex real-world problem

Table 1 continued

C Context/general		
Phase	Issue	Obstacles
2.2 Project planning	*2.2.1 Start with the synthesis* Follow the principle of backward planning and the satisfying principle (the goal is to acquire a minimum amount of information which is sufficient to provide a satisfying (Wiek and Walter 2009) answer to the guiding question	The project team has not the experience or sufficient cognitive and management abilities to design a forward operating project plan based on a guiding question which includes key elements such as evaluation criteria, participating stakeholder groups, system variables, and boundaries
	2.2.2 Define a project end Clearly define when, how, with what products for whom the project will be ended	The results ask for post-processing and double science-practice peer review, participants may become disappointed because they expect results too early
	2.2.3 Methods of knowledge integration Methods for system representation, system projection, system evaluation, for the five aspects of knowledge integration (Scholz and Steiner 2015; see Fig. 4) and for overall synthesis have to be selected	Not enough attention is paid to the prerequisites of applying the methods which may ask for special method knowledge and time for applying (which will be saved later by easier interpretation and consensus building)
	2.2.4 Consented time schedule The schedule has to fit to fit to the needs of practitioners (e.g., farmers crop cycle, politicians) and scientists	Scientists are not available at the time when stakeholders are available. The science team is not willing or able to adjust to the schedule of the practitioners?
2.3 Organization	*2.3.1 Organizational chart* The responsibilities and involvement of science and practice as well as the project structure (system model/facets) should best become visible in a double-wing organizational chart	Not enough resources are available to include all key stakeholders, in particular, for the subprojects (some parts of the study do not meet criteria of transdisciplinary project management)
	2.3.2 Stakeholder pre-selection Who should be ideally targeted in an actor analysis	Stakeholder involvement follows just snowball (chain referral sampling)
	2.3.3 Physical separation Are the members of the case study critically separated?	The internet-based online communication is not fail-safe enough, the numbers of physical meetings with stakeholders is too low
2.4 Resources	*2.4.1 Financial resources planning* The financial, material, organizational, spatial and human resources reliably have to be transparently assessed at the beginning of the project	Rapid changes of the schedule may not be followed by proper financial flows and not enough money for the project is available in time? Industry financing is vulnerable with respect to personal changes in industry
	2.4.2 Personal fluctuation Large-scale and long-term processes ask for emergency scenarios if key actors leave the system	Longer (multi-year) transdisciplinary processes are endangered if they do not include a multistage research plan
	2.4.3 Career constraints Does the participation in the case study support the participants' professional careers?	The project team forgets to negotiate, formulate, and communicate these rules and does not ask participants to sign them
	2.4.4 Confidentiality and trustworthiness Are there rules which support a "protected discourse arena"?	The project team is forgetting to negotiate, formulate, communicate and ask for signing these rules to or by all participants
3. Core phase		
3.1 Stakeholder (public at large) involvement	*3.1.1 Collaborative stakeholder identification and selection* What stakeholders and scientists have to be involved to develop sufficiently good outcomes	The project does not conduct a formal/method-driven actor analysis on what representatives with what relevant expertise and "stakes" should be involved? By what method are the stakeholders elected? (Reed et al. 2009)
	3.1.2 Joint system representation Is there a jointly understood language/representation?	There is no common representation such as a flow chart which is seen as the common core representation; people who join the project later often have severe difficulties to consider the transdisciplinary process as "their project"
	3.1.3 Stakeholder ownership Do stakeholders take ownership about the case study by co-authorship, presenting the study as their own study, etc.	Formal means of supporting acquiring stakeholder ownership by co-leadership, communicating joint responsibility to the public, etc., have been not used

Table 1 continued

C Context/general		
Phase	Issue	Obstacles
3.2 Methods	*3.2.1 Selecting methods* A transdisciplinary process needs methods of knowledge integration, system representation, scenario construction (scenario) evaluation; the synthesis strategy should be consented	The specific expertise, sufficient time and resources for applying core methods are not applied
	3.2.2 Selection of scenarios, evaluation perspectives, and evaluation criteria The question of what scenario should be evaluated by what stakeholder groups, what evaluation criteria are chosen, what material flows should be focused should be jointly reflected and decided by scientists and practitioners	The co-leader and the steering board do not have acquired sufficient insight in how the methods work (Scholz and Tietje 2002) and, thus, are not interested or capable of integrating various types of knowledge meaningfully
3.3 Communications	*3.3.1 Public relations* During the core phase, the public may be informed about the process, but not about the results as these have to be checked at the end of the process and have to be consented/checked by the participants	Both, the principles of a protected discourse arena and principles of research do not really allow for transmitting preliminary results; however, the public media may ask for preliminary results
4. Post-processing		
4.1 Outcomes	*4.1.1 Integrated functional system model* Knowledge about the facets (i.e., subsystems; see 2.3.1;) have to be checked and integrated by quantitative and qualitative methods; the system model should be a coupled human–environment system model (e.g., including flows and actors)	People are interested in information which is easy to digest, thus the presentations rather tends to report single (variable) outcomes from the study or subprojects
	4.1.2 Socially robust orientations Elaborating jointly elaborated and agreed "socially robust orientations" among scientists and practitioners; knowledge integration may be supported by formal methods	The joint development of socially robust orientations (which also include a priority of actions and policy means) is not conceived as a separate phase among the participating key stakeholders and scientists that supplements report writing
	4.1.3 Double peer review of results/orientations The reports about the study as well as the scientific papers ask for peer review from science and practice	The peer groups (scientists, participating stakeholders, public at large), form (e.g., printed vs. web) and function (documentation, learning, promoting action, etc.) are not sufficiently defined
	4.1.4 Scientific papers Papers may be published on the (i) issue dealt with (e.g., sustainable vegetable production), (ii) the process (e.g., the farmers' learning in a transdisciplinary process), or (iii) about the methodology of transdisciplinary process	Scientific journal papers do not allow to write papers which combine (i) to (iii) because of volume and readership interests
4.2 Dissemination	*4.2.1 Joint communication of results* There are various ways of communication: one is the public media, another a report and network activities/meetings to convey the main results to key stakeholders	The project leaders have to deal with the tradeoff that the public may want the results early, whereas the valuation, interpretation and integration of results and science review takes much time
4.3 Evaluation	*4.3.1 Outcome evaluation* The outcomes, i.e., what has been learned and what has been changed should be determined/measured. The results need double reviews from practice and science	It is difficult to (objectively) assess whether decisions are made because of the transdisciplinary. It is challenging to go beyond face validity (i.e., to apply formal methods)

protected discourse arena can be developed. The cultural dimension here interacts with the contestedness and the reflexivity of the stakeholders. If we look, exemplarily, at nuclear waste disposals, there may be only a few countries in the world in which the nuclear power industry and anti-nuclear activists might join a protected discourse arena (C1.4) and cooperative learning might be developed (C1.5). However, this has been possible in Switzerland and Sweden (Scholz et al. 2007, 2009). The Swiss-Wellenberg study aimed to find a policy process (not a technical solution) for nuclear waste disposal that would be accepted by most residents. The Canton (i.e., state) of Nidwalden had declined an underground repository after fierce, highly emotional, and, obviously, non-functional policy processes. In this transdisciplinary study, no co-leadership with legitimized decision-makers could be established for a multi-stakeholder process. In the Wellenberg case, although the president and all ministers were personally interviewed in the initiation phase, the government of Nidwalden refused the call for co-leadership. Thus, a proxy co-leadership formed by a former state president and the current female chairman of the parliament took this role. The case also provided an extreme example, even in a highly democratic country such as Switzerland, of the difficulties of building a protected discourse arena. Furthermore, presumably a hundred or more telephone interviews and more than 40 individual meetings were needed to receive commitment from the two proxies (see above) to participate in meetings of the multi-stakeholder discourse. The contestedness of this case is highlighted by the fact that many participants entered the meetings secretly via a back entrance. Written rules of the protected discourse arena were distributed at the meeting and everyone involved was required to explicitly agree on them.

The initiators of a transdisciplinary discourse have to thoroughly consider whether the social system allows cooperative learning to take place and, if so, under what constraints (C1.4 and C1.5). Self-perception and expectations (C1.6) as well as reflexivity (C1.7) are important constraints. This holds true both for practitioners and scientists. Statements by industrial practitioners, such as, "My task is to produce and to sell carpets and not to think about the future of my home village" correlate closely to statements by researchers, such as, "I am a scientist and have to write papers and am not paid for participating in a transdisciplinary process." The latter also reflects institutional constraints (C1.8). One can also find practitioners and scientists who understand and appreciate transdisciplinary processes. However, based on lack of knowledge or for other reasons, the institution may not (sufficiently) support a planned project.

Though transdisciplinary processes deal with pertinent and pressing problems, for example, day-to-day issues such as the development of a certain town's environmental pollution or resources management or value-related issues such as animal or landscape protection, there are various reasons why the study should not deal directly with day-to-day politicized issues (C1.9). Practice shows that one may deal with the problem on a slightly abstracted level or shifted perspective. If, for instance, the public and private key stakeholders participate in mediation on how a brownfield might be remediated and developed, a transdisciplinary process might build agreement on what principles and direction a remediation or master plan should take. However, the full description and negotiation of the details that may have to precede a vote by a municipal parliament is not a subject for a transdisciplinary process (see Scholz and Tietje 2002, p. 223).

Beyond the general issues and related obstacles which refer to a society's preparedness for a transdisciplinary discourse, authenticity is crucial for transdisciplinary processes at various phases, from defining the guiding question to a joint dissemination (4.2) and evaluation (4.3) of the outcomes of the transdisciplinary effort. Particularly, this encompasses an authentic co-leadership, which is also part of building partnership (1.2); the acceptance of the otherness of the other, which is not only important for societal preparedness (C1); and sufficient incentives and values as drivers to participate over the full transdisciplinary process (1.2.2).

Initiation and preparation phase

In any project, the initiation and preparation are the most important and delicate phases. Usually, the knowledge about a system is at its lowest point, and the likelihood of making errors is at the highest level, and fundamental mistakes in either phase have a low chance of correction. In many of the ITdNet projects, the initiation and preparation took 6–24 months, whereas the core phase took only 3–6 months. For the authors, the building of co-leadership among practice and science at all levels of the project (1.2.1) is the most crucial feature. Yet developing a consensual vision and a proper guiding question (1.1.1, see also Fig. 2) together with the challenge of identifying and sketching added values (1.2.2) for all stakeholder groups are similarly important. This often is linked to thinking about variants of objectives and systems.

Usually and in many projects, the basic rules of communication (see also C1.4 and C1.9) and of the process are negotiated and become fixed. These include that different roles and divergent opinions related to an issue are to be accepted (1.2.3), as long as they follow basic rules of society (such as a national constitution or the principles of human rights). Sustainable transition often calls for out-of-the-box thinking and thus for properly including unconventional thinkers (1.2.4). Special rules have to be established for crisis management, e.g., when certain participants violate these rules. A highly sensitive aspect of the initiation phase is the access to data that are generated in the transdisciplinary process. Some data may be personally, economically, and/or politically sensitive. The ownership of the data must be clarified (which is different to contract-based research) as well. Further, access to the data once the study ends is an important issue. In an intercultural study with various ethnolinguistic groups of the Maya, the science team had to agree that because of the basic rules and the endangerment of their culture, the council of Mayan elders had to decide after a ceremony (when reading the signs of the Lord) whether some data (on interview) should be published. This is an example of genuine uncertainty about access to data in a transdisciplinary process.

The transdisciplinary processes of the ITdNet were framed as *projects* (and not as, e.g., initiatives). Thus, they were temporary, and the *general rules of project management* were applied. The reality of an effective, realistic transdisciplinary process includes representatives of all key stakeholder groups in a process of joint problem definition (2.1.1) enriched by experiential case encounters for those who lack sufficient system literacy; an explicit description of a guiding question (2.1.2), which is "visible" (such as an identity card) throughout the whole process; and a faceting of the case from which workable subprojects are defined become possible (see Scholz and Steiner 2015; Fig. 3), whose results may be integrated for deriving a satisfactory answer to the guiding question. Based on these, the system boundaries may be defined (2.1.4), and a system model may be developed that needs to be understood and shared by all key stakeholders. The model of a supply–demand chain (Scholz et al. 2014, p. 47) or an actor-based material flow model (Binder et al. 2004) might serve as examples. For all these activities, a joint language that can be understood by all participants is a necessity (2.1.6).

We learned very early that project planning must start by identifying what knowledge has to be integrated and how to develop socially robust orientations that can be related to the guiding question (2.1.2). This calls for defining the outcomes and products of the project (2.2.2) and carefully choosing or developing methods of knowledge integration (2.2.3). A highly critical issue is agreeing on a time schedule, as the agenda of the key stakeholder groups and that of the scientists may essentially differ. The organizational chart is another page of the identity card of a transdisciplinary process. Many of the organizational charts have two wings, a practice and science one, a leadership level including project leaders, steering board and advisors, and a sub-project level including practice and science leaders on the levels of facets/subprojects of the projects.

The process is based on financial and personal resources (2.4.1 and 2.4.2). The challenge of personnel fluctuation is part of emergency management. In particular, in multi-year projects, external (industry) funding may depend on personnel fluctuation and may result in projects being shortened. We often experienced that if a practice (or science) leader is departing, his or her successor may hesitate to take on the co-leadership role for various reasons. In any case, the personal incentives have to be critically examined also with respect to the career interests on both sides, practice and science (2.4.3; see also C1.4). The start of any transdisciplinary process is based on personal confidentiality and trustworthiness (2.4.4), which are often attained through informal processes. Who the proper persons are for a transdisciplinary process is usually (untidily) assessed by informal, snowball-sampling-based assessment but may also be more broadly conducted.

Core phase

Many issues of the initiation and preparation phase are (spirally) repeated in the core phase. These include collaborative stakeholder identification and selection (3.1.1), and the need to choose a language for joint problem representation (3.1.2). In practice, the identification of the stakeholders is usually a blend of top-down and bottom-up procedures. For example, after specific stakeholders were already selected as part of the joint development of a system model (2.1.5), an extended stakeholder identification might occur in a consecutive next working step as well, because involved stakeholder groups may suggest others, followed by a snowballing process. At best, stakeholders should consider themselves to be (responsible) members of a transdisciplinary project/process (3.1.3).

In practice, we can find many transdisciplinary studies that have used formative methods such as area development negotiations (applied in Scholz and Steiner 2015; Fig. 4), material flow analysis, supply chain analysis as a basic method of system integration, and knowledge integration (3.2.1). Other projects have developed complex models of integration (see Supplementary Information) that resemble Figs. 1 or 4 in Scholz and Steiner (2015) and go back to the Brunswikian idea of knowledge integration by bootstrapping cues (Karelaia and Hogarth 2008). The project management faces a tradeoff between using these methods (which may not properly include the most salient and innovative issues) and less structured proceedings (which has a high risk of ending up with seemingly arbitrary conclusions). An important issue is that the key stakeholders who have participated in problem- and system definition are or become sufficiently literate regarding methods and various opportunities to bring in their knowledge and experience for, e.g., constructing and evaluating future scenarios (3.2.2). One may consider this as a prerequisite for the stakeholders' active participation in the process of knowledge integration and formation of socially robust information in the post-processing phase (see 4.1.1–4.1.2).

Communication during the core phase is sandwiched between receiving public attention (i.e., receiving as much social impact as possible) and the rules of a protected discourse arena and solid scientific and project work that allows for the release of the results after all the work, including a critical review (from both practitioners and scientists), has been accomplished. A first communication of results usually takes place at a closing event in which preliminary first results are publically communicated and the media provide the initial information about the expected outcomes.

Post-processing

Much work, which may last between 6 and 18 months, has to be done after the termination of the core phase. In general, we may distinguish between an improvement of the system knowledge (4.1.1) and the generation of socially robust orientations (4.1.2). As mentioned in Part I of this paper, the new knowledge is part of capacity building whereas socially robust knowledge includes consensus building which may be considered as a component of the formation of social norms. The key stakeholders may be motivated to take new options, to rethink strategies, or to be confirmed in their actions. Swiss railways stopped selling their hydropower plants after the results of the dynamic and uncertain prices and impacts of cheap fossil energy were elaborated (Scholz et al. 2001). Or a pre-alpine community launched a new, large-scale, farming-oriented family holiday village right after the termination of a case study (Scholz et al. 2002). Though case agents might be convinced that these decisions could be attributed to a transdisciplinary process, there is yet no scientific method that allows one to quantitatively assess the impact of a transdisciplinary process (4.3.1). There are also relatively few thorough evaluation methods. However, Walter et al. (2007) applied the statistical mediation technique to show that stakeholder capabilities are fostered by participating in a transdisciplinary process, and Njoroge et al. (2015) took a classical control-group design approach to show how much Kenyan smallholder farmers' yields were improved by a transdisciplinary process.

Naturally, the dissemination of the findings is part of the post-processing phase. On the practice side, this is done by the key stakeholders who participated. Thus, from a science perspective, there is no need to implement the results in practice. The practitioners are also strongly involved or co-authoring the project report based on a double practice–science review.

Finally, as common for an academic paper, there are multiple outcomes for science. Students as well as junior and senior scientists can learn a lot, collect data, and gather multiple scientific findings about theory and practice collaboration, complex project and system management, transdisciplinary processes, and the topics and issues with which they have been concerned. The presumably most efficient study (considering publications) produced two case-study books (for the public) and four scientific papers in highly ranked journals. Several industry-based research projects followed and 38 master's degree students gained an average 16 credit points each, which may be considered equivalent to about a fourth of a 2-year master's program. Whether or what groundbreaking knowledge has been gained and what pioneering decisions of the practitioners were factually made is difficult to assess and finally would call for a thorough case-based analysis.

Discussion

With the focus on transdisciplinary processes which are applied to complex real-world settings, we identified a set of generic key obstacles that were identified when pursuing 41 mid- and large-scale studies. Small-scale transdisciplinary processes, for instance, a master's degree thesis with time and financial constraints, are not discussed and may call for specific adaptations. Factually, there have been very few successful studies of transdisciplinary projects that have been run independent of mid- or large-scale transdisciplinary processes (Günther 2004).

From a methodological perspective, this review and discussion are based not on an "independent observation" but rather originate from reflecting and reporting on two decades of experience in initiating, planning, participating in, co-leading, observing, and appraising transdisciplinary research, which supplemented and sometimes complemented the basic and applied disciplinary research of the authors.

The discussion does not follow the course of transdisciplinary processes. We organize it around seven fundamental, critical, and pivotal questions that have shaped many instructive and, often, exit discussions among proponents and opponents of Mode II transdisciplinarity.

What is the added value for science and practice for engaging in transdisciplinary processes?

The proof of added value is basic for both (i) motivating stakeholders to invest in and to participate in transdisciplinary process (see Table 1, 1.2.2) and (ii) convincing universities, the public, and funding organizations that something additional may result that goes beyond classical "science shops" (Leydesdorff and Ward 2005) that focus primarily on knowledge transfer for (alternative) citizens' questions and empowerment as well as a community-based economy.

Our opinion is that, given a socio-political context that allows for transdisciplinary processes, it is not difficult to motivate representatives from public institutions and industry (e.g., owners of brownfields, land, or farms) to participate and to take co-leadership if there is a tangible, (ill-)defined problem that they want to master and if there is a strong, legitimized decision-maker. Further, scientists might show practitioners how they can benefit from learning and accessing new subject knowledge, methods, and methodologies about how to approach such a problem. A prerequisite for this is that the science team has sufficient knowledge and methods in their tool kit to complement what practice has to offer.

Let us illustrate this with several examples of benefits for industry and public authority partnerships. Swissnuclear (a subgroup of the association of large Swiss electric power companies known as Swisselectric), which is also responsible for nuclear waste management (together with NAGRA, a company-owned cooperative), had developed technical solutions for depositing nuclear waste (see case study No. 15, Supplementary Information I). However, the Swiss nuclear industry was missing the conception of a policy process on site selection. The organization had insufficient knowledge about how the conception and how the risks as well as the safety of the underground deposits might be communicated, and how a multi-stakeholder discourse should be framed. Here, transdisciplinary processes became attractive. A prerequisite for a partnership was that the state-of-the-art engineering knowledge about nuclear risk assessment (Junker et al. 2008) and psychological risk perception were available in the science project team. Swissnuclear and the Swiss process on nuclear waste disposal management benefitted by gaining knowledge about what decision processes are preferred (Kruetli et al. 2012) and how the risk perception looks like (Krutli et al. 2010; Moser et al. 2012a, b, 2013; Scholz et al. 2007).

The Global TraPs (Global Transdisciplinary Processes on Sustainable Phosphorus Management) was the first, global-scale transdisciplinary, industry-based study on resources management (taking phosphorus as "a learning case") and included representatives of all key stakeholders of the supply–demand chain that served as a basis for a comprehensive system model. Thus, a wide range of stakeholders from mining companies, fertilizer producers, and farmers to UNEP, FAO, and Greenpeace participated (Scholz et al. 2014, 2013). The leaders of industry associations, e.g., the directors of the International Industry Fertilizer Association (IFA), were facing a couple of challenges, including conflicting views (in science and among science and industrial actors) on the scarcity of phosphorus, slow technology development for improving the quality of fertilizers, and the discussion about environmental threats. One of the outcomes of the Global TraPs project was that 51 people (as part of the whole project team)—among them 18 practitioners ranging from phosphorus mining companies to the US Geological Survey to Greenpeace—published a comprehensive system analysis titled "Sustainable Phosphorus Management: A Global Transdisciplinary Roadmap" (Scholz et al. 2014b). This system analysis can be used for developing policy options for changing phosphorus flows. The scarcity discussion was vitalized and enhanced by a scientific contribution in high-ranking journals. This "phosphorus scarcity hypothesis soon" has been rejected by thorough analyses including industry knowledge (Anonymous Referee #2 2014, 2014; Cook 2014; Edixhoven et al. 2013, 2014; Hilton 2014; Scholz and Wellmer 2013, 2014). Conflicting assumptions, misperceptions, and errors underlying certain (premature scientific) modeling efforts and transdisciplinary resources system knowledge became evident.

Almost all, if not all, of the co-leaders and key players involved in the reference studies have been highly satisfied (if we refer to the oral feedback or the statements on prefaces of the reports). However, the possible outcomes in regard to what would not have happened without a specific transdisciplinary process are difficult to assess. Often—and we believe that this happens in any case study—key stakeholders claim that a certain action would not have taken place without the transdisciplinary study, but this is scientifically impossible to prove on the basis of a single case.

What do cost efficiency and evaluations of transdisciplinary processes look like?

The evaluation of transdisciplinary processes is a special methodological challenge. Most studies are single and multiple case studies. Thus, in the language of statistics, we speak about *one observation* or about *a few replications* of inhomogeneous entities that do not allow for statistical hypotheses testing.

However, there are several—rarely applied—options for using inferential statistics. The capacity building of the participants of the above-mentioned Appenzell study was evaluated when adapting the statistical *mediation technique* (Baron and Kenny 1986; Preacher and Hayes 2004). The enhanced decision-making capacity (as the outcome or predictor variable) was related to the procedural and product-related involvement of the stakeholders (called outputs, such as the number of hours spent in a transdisciplinary process) and theoretically assumed intermediate effects (such as acquiring additional system knowledge and changing environmental values). This statistical method proved that network building and transformation knowledge significantly increased as a result of stakeholder participation (Walter et al. 2007). Another option involves a kind of lead indicator of the success of a transdisciplinary process, and one may embed a statistical design in a transdisciplinary study. This is the key idea of Lewin's experimental action research and was applied by Njoroge et al. (2015) in a transdisciplinary study on improving smallholder farming in Kenya. Here, the yield (measured in kg maize) was taken as a performance variable, although capacity building of stakeholders certainly had to be conceived from a much broader perspective.

The economic efficiency of a transdisciplinary process also matters. In some of the mid-sized ETH-NSSI case studies, the expenses of the scientific team and the salaried costs of practitioners' and scientists' working hours were assessed. Here, the results were often in the low seven digits in USD. Naturally, we are facing an allocation problem, as the study included teaching (e.g., approximately 600 student credits, equal to about five 2-year master's degree programs), equivalents of various research papers, and strategic planning on the side of the practitioners. However, the cost efficiency of transdisciplinary studies may deserve more attention in the future.

What is the added value of transdisciplinary processes compared to other conceptions that promote the interface of science and society?

Transdisciplinary studies include elements of participatory research and resemble some forms of action research or 'real experimentation' (Schneidewind and Scheck 2013) and some forms of participatory (strategic) planning. Thus, a critical question is what makes transdisciplinarity unique. We suggest that the phrasing *from science for society to science with society* (Scholz and Stauffacher 2009) *by mutual learning among science and society* (Scholz 2000), based on *knowledge integration by means of quantitative and qualitative methods* (Scholz and Tietje 2002) for *developing socially robust solutions* (Gibbons and Nowotny 2001) by *capacity and consensus building* among all key stakeholder groups (Scholz and Tietje 2002, Susskind et al. 1999) for *coping with ill-defined problems* may not apply to any other methodology. We argue that such a methodology is needed to identify sustainable transitions that target *resilient, coupled human–environment systems* (Scholz 2011; Seidl et al. 2013). Here, the environment includes the material–biophysical–technological systems as well as biophysical and socio-cultural systems. We note that ill-defined problems (usually) do not allow for solutions but rather transform problems. Thus we speak about socially robust orientations instead of solutions (see Part I of this paper).

A vision of discipline-based interdisciplinary processes in transdisciplinary processes (Schaltegger et al. 2013; Scholz 2011) for supplementing the systems of other forms of knowledge production is crucial. Factually, transdisciplinary processes call for the creation of new forms of institutions, such as a transdisciplinary university (Jantsch 1970) or a college of transdisciplinarity (Scholz and Marks 2001). Coping with complex, real-world problems in this Anthropocene age requires a broader institutionalization of these processes. Unfortunately, this vision yet has to be elaborated based on these factors.

Do transdisciplinary projects create a new type of legal entity?

Mode II transdisciplinary processes deal with tangible, real-world problems. Inappropriate priority settings, dysfunctional orientations, or wrong actions or solutions may result in the accountability, responsibility, or damaged reliability of scientists, or even their culpability if stakeholders claim that these erroneous or ineffective actions or errors have resulted from scientists' recommendations. The tangible issues in the reference set range from new zoning regulations allowing/forbidding some new houses as a follow-up to an urban study (Scholz et al. 1996) to a national railway company's decision to sell hydro-water plants and switch to cheaper, coal-based power (Scholz et al. 2001) to the elaboration of methods for determining the placement of a nuclear waste-disposal facility (Scholz et al. 2007). Here, the *distinction of roles*, e.g., between legitimized decision-makers and scientists, is important (see Scholz and Steiner 2015; Fig. 2).

The delicate legal status may also be reflected by the difference between *recommendations* and *orientations*. Recommendations are the product of consultancy and—depending on the national law and contractual status—an advisor may become liable for his recommendations. This is why many investment organizations do not provide recommendations. However, even if a transdisciplinary study team provides only orientations, there is some level of accountability and responsibility of scientists and practitioners that may induce a *moral responsibility* or dilemmas such as those faced by Robert Oppenheimer and other physicists of the Manhattan Project, who did not build but invented the basic mechanisms for an Atomic bomb that erased thousands of human lives. Based on the experience of more than two decades' worth of case studies, the suggestion that "joint decision-making" is the highest level of transdisciplinary activity (Wiek 2007, p. 55) is practically unfeasible, legally critical, and socially questionable. If a *university is considered a public good,* it should in principle serve all groups and members of a society.

The access to and *ownership of data* is another delicate issue. Here, we may distinguish between data that become accessible before a study is started and data that are generated in the course of a transdisciplinary process. Here, the question of who owns the data arises. If there is a formal co-leadership, the access, validity check, and potential public access to data must be agreed upon as in any research project. This may mean that the university and not the researcher is the owner and—in the event of an institutional change of the scientific co-leader—access and ownership may change. The hybrid character of data may become even more challenging if the project includes students who may get access to sensitive data or who may be exposed to certain risks. Similar problems may arise in funding, as the openness of a transdisciplinary process as well as the imponderabilities of case dynamics may alter the topic, the partnerships, and the goals.

What role conflicts do participants of td processes face? Transdisciplinary processes as a tool for democracy

In their interactions with the public and with one or more stakeholders in particular, scientists are expected to take a neutral position if they are dealing with issues of serious public concern. They will often be asked to take a scientific perspective and to provide objective system descriptions of environmental risk, pediatric research, or economic development. Here, the label *reflexive scientist* (Pohl et al. 2010) is appropriate. In terms of the history of science, one may phrase this by saying: The scientist is expected to provide descriptions based on "a perspectival objectivity …. [when] eliminating individual (or occasionally group) idiosyncrasies" (Daston 1992, p. 597) and personal political valuations. The university and its scientists become change agents (Stephens et al. 2008) by providing knowledge to all.

But scientists who deal with applied topics such as the interaction of science and technology are also "called upon to play the role of a '*policy expert*'… who dips into the closed worlds of Washington" (Jasanoff 1996, p. 393). When running transdisciplinary processes, independent of the specific level of degree of co-leadership, the first author was mostly responsible for the *facilitation* of the process, i.e., the moderation and knowledge integration methods. The studies usually dealt with conflicting issues. Thus, *analytic mediation* became part of the facilitation process. The area development method, which links scenario analysis and multi-attributive utility measurement, was developed as a method of analytic mediation. However, working as an elected professor of the Swiss Federal Institute of Technology (ETH), it is clear that, by affiliation, the scientist became a promoter of the Swiss constitution (the professors of ETH were, for instance, formerly directly elected by all ministers of Switzerland).

In reality, the different roles may overlap, interfere, or exclude each other. The scientist involved in transdisciplinary processes is continuously challenged to reflect and to communicate upon the role of his judgment. Here, also, the distinction between transdisciplinary processes and transdisciplinary research may be important, as not all activities of scientists (such as administration) can be called research. Transdisciplinary research is conceived as real-world, problem-oriented, interdisciplinary research which develops methods, theories, and subject-related knowledge on the issues and processes dealt with or taking place in transdisciplinary processes.

The facilitation of a transdisciplinary process (if there are no specific research questions and elements that call for a researcher to take this role, e.g., the role of a participating observer) might well be accomplished by certain professional consultants (see, e.g., Njoroge et al. 2015).

Naturally, we have to be aware that scientists today—as they have throughout history—play further roles and that the social structure has affected structures in science. We may occasionally observe that scientists consider themselves forerunners of a *great transition*, motivated by the inner belief that they have investigated and understood what sustainability is all about and how it may be attained. As extreme examples, scientists became political activists in America in the 1930s (Kuznick 1987), others had a distorted ethical view such as evidenced by Nazi medicine (Barondess 1996), or supported a social program of the Bolshevik Revolution (Krementsov 2006). We should acknowledge that transdisciplinarity is also bound to a socio-political context (see Table 1) that is a pluralist (with respect to opinions, values, religion, ethnicity, disciplines, and perhaps also logic), democratic setting.

We may consider a shift from single, expert-based decisions towards participatory elaboration (Stirling 2008). Unfortunately, the term participation is often used without specifying who is participating in whose venture. Transdisciplinarity is characterized by a specific role that scientific knowledge plays as a public good in a knowledge democracy (Bunders et al. 2010). Historically, this approach has its roots in Merton's (1996) claim that science in a democracy calls for a certain ethos or culture that includes honesty, freedom of inquiry, and a basic pluralist view, as sketched in Fig. 1. In this conception, *transdisciplinary processes may be considered a tool for democracy*. This includes a joint-problem definition by including the key stakeholders related to a problem as well as utilizing methods not only for building consensus, but also for identifying consent and dissent among stakeholders. This may serve politicians well in understanding the scope of societal demands for designing resilient human–environment systems. We may conclude that transdisciplinary processes can only be applied if the key stakeholders are able to practice basic discourse processes as in Western democracy and that vice versa transdisciplinary processes may well be considered as a supplementary policy tool in democratic societies. The successful intercultural case of transdisciplinary discourse about genesis and conception between six Guatemalan ethnolinguistic, indigenous Maya groups and European oncologists (Scholz 2012) showed that transdisciplinarity is not bound to constitutional democracy. Issues such as the acceptance of the otherness of the other (see Table 1 C1.4; 1.2.3), trust in the process, given a certain preparedness for change (see C1.1) may be seen as the basic prerequisites.

Evaluating outcomes for practice and for science: does the difference between normal and post-normal science matter?

In evaluating Mode 2 transdisciplinarity projects, both the quality of the *process* and of the *outcomes* are of interest. Thus, the quality of the process is a prerequisite of high overall quality of a study. A transdisciplinary process should promote better decisions and/or actions by practitioners and innovations in science. The search for a scientifically intriguing and socially significant guiding question, the involvement and mutual learning of key stakeholders and practitioners, and real co-leadership as well as socially robust orientations based on an application of sound, method-based results can all be considered main outcomes of a transdisciplinary process. Although real-world situations are unique (and cannot be repeated as observations in an experiment), the methods and proceedings of transdisciplinary processes should be described in a way that allows for replication. From a Mode II perspective, the main outcomes are (i) capacity building and (ii) consensus building on where to focus and how to better make decisions for sustainable transitions; (iii) how to deal with those members of a system who are negatively affected (mediation); and (iv) how to provide arguments for politicians to establish suitable policies and regulations to sustainably cope with the problems related to the guiding question. A scientific challenge is to evaluate these four aspects or functions of transdisciplinarity.

C*apacity building* may be evaluated by ex-post statistical methods (Walter et al. 2007) and/or embedded statistical evaluation design (Njoroge et al. 2015). However, usually the qualitative method of face validation is applied, and most evaluations are based on peer reviews (Zscheischler and Rogga 2015). A qualitative evaluation is often unsatisfactory since "there is not yet a well-established community of peers who are experienced in reviewing the quality of TD endeavours" (Wickson et al. 2006, p. 1055). Evaluations are often provided by peers who have never participated in or co-led a transdisciplinary study, and because of this, the evaluations of transdisciplinary projects are confined to what is published in papers and exclude what has been produced by the process (for science and society) and their impacts on practice. The current appraisal of transdisciplinarity is also biased, as there are many projects that are conducted under the label of transdisciplinarity, but involve only multi-stakeholder discourses or reports about interviews with some of the involved stakeholders. And other studies even do not differentiate between interdisciplinarity and transdisciplinarity.

The evaluation of transdisciplinarity is far from having a single level or grade for accessing the quality of a study. However, in theory, the understanding of the different products (see above) such as the quality of the process is increasing. We believe that some of the items presented in Table 1, such as the classifications in a couple of recent papers (Jahn et al. 2012; Klein 2008; Lang et al. 2012; Scholz 2011; Scholz et al. 2006; Zscheischler and Rogga 2015), may well serve to develop a more formal method that can evaluate components or profiles of strengths and weaknesses. This may be done in a way similar to impact profiles of LCA profiles (Guinée, 2002). A scientific challenge is to elaborate prototypical profiles of transdisciplinary processes to better understand the specific ways in which transdisciplinarity has unfolded in a specific project. Such an evaluation may well include quantitative assessments (e.g., regarding the completeness of stakeholder groups, the number of participants, etc.) as well as qualitative assessments (such as whether the guiding question has the potential to promote groundbreaking innovations).

If we aspire to discipline-based interdisciplinarity in transdisciplinary processes, an important standard is to achieve "textbook state-of-the-art knowledge" in all conclusions. This may become a challenging issue calling for proper team building and a multidisciplinary peer review of the products of a transdisciplinary process. Sometimes, findings related to the topic dealt with in a study may be published in disciplinary journals; this shows that (some) disciplinary standards are met. However, the complexity of real-world problems requires multifactorial and multidisciplinary or interdisciplinary causation, which also have become subjects of evaluation in this field (Stokols et al. 2008). Here, we may ask for quality standards for interdisciplinarity and Mode 2 transdisciplinarity in the synthesis process.

An interesting question in this context is whether the quality standards differ between *post-normal* and *normal science* conceptions. When facing the *complexities* and *uncertainties* of challenging real-world problems, post-normal science focuses on society-based evaluation criteria and acknowledges that scientists may include values in their reasoning (and thus do not aspire to serve all stakeholder groups equally, e.g., when taking an environmentalist position). Post-normal scientists widely follow a liberal, anything-goes perspective when discussing methods and often abandon standard principles of (evidence-based) verification in complex real-world settings. From a sociology of science perspective, it would be interesting to investigate whether and in what form post-"normal" scientists become more value-driven change agents than do "normal" scientists.

We suggest that *a functional, adaptive normal-science view* may help scientists to become change agents by making science available to all stakeholder groups. This usually calls for sound inter- or multidisciplinary research when meeting or adapting disciplinary standards and has been often accompanied by use-inspired basic research that includes participatory research and focuses research on topics evolving from societal challenges. System theory may help in Mode 2 integration and may help normal (disciplinary) scientists with a certain level of sophistication to better identify and apprehend the genuine uncertainty inherent in causal textures of complex physical and social environments. There are *irreducible uncertainties* in any cognitive model related to a complex real-world environment (Nicolescu 2006), but human knowledge about complex systems is genuinely incomplete. Thus, we argue that the difference between normal and post-normal sciences is not as critical from a functional, societal, Mode 2 perspective. However, we would venture to say that, in the reality of transdisciplinarity, a normal science approach may appear much more structured and tends to include more method-based approaches and standards of validation and evaluation than the post-normal approach.

The difference between normal and post-normal science seems to be more fundamental if we consider how the incompleteness of knowledge (i.e., the unknown) is dealt with. Following the history of science, normal science will strive for new basic and applied theories and meta-theories (including extended forms of logic that may properly allow for phenomena such as Russell's paradox). The strategy that post-normal science may take seems open for discussion. The strategy of the physicist Nicolescu (2014) to postulate a spiritual layer (thus including supernatural entities) certainly leads beyond science, but is finally linked to a specific form of subjectivity. Nicolescu (based on insights into quantum mechanics) postulates a "totality of reality" that integrates different (discontinuous) levels of reality and relativity (and causality) that "create a new perspective on religion, politics, art, education, and social life" (Nicolescu 2006, p. 6). We think that the genuine incompleteness and inconsistencies that science encounters may well be approached from a (reflected) objectivist perspective when constrained validity is assigned to different types of reasoning, as presented in this paper.

Propositions on the nature and practice of transdisciplinarity

We conclude with ten propositions. Five of them comprise the key messages provided in the section on the ideal type. These propositions reveal that transdisciplinary processes provide a new perspective for utilizing and relating experientially formed stakeholder (or real-world experts) knowledge and expertise with high-quality interdisciplinary knowledge that has its roots in the rationales of different types of disciplines. This has been expressed by the phrasing that we need disciplined interdisciplinarity in transdisciplinary discourses. This new demand emerges from the complex, multilayered socio-technological problems caused by the current stage of human evolution. We have created this Anthropocene age and a globalized, socioeconomic system including new types of complexities, ambiguities, and ignorance about how certain basic material–biophysical environmental and socio-cultural processes may develop. We argue that transdisciplinarity is thus an emerging form of utilizing and generating scientific knowledge that has the potential to become a main pillar of the scientific structures and institutions of the twenty-first century. The theoretical propositions read as follows:

1. *Transdisciplinarity* integrates different types of causation (reasoning) and different types of epistemics (see also Fig. 3). This is, in particular, necessary if a horizontal integration, for instance an *interdisciplinary* approach merging concepts and theories, is not possible and/or no *cross-disciplinary* language (such as mathematics) may be applied.
2. We may distinguish between *Mode 1* and *Mode 2 transdisciplinarity*. Mode I transdisciplinarity is an inner-science activity (see Scholz and Steiner 2015; Appendix). It is needed to overcome (logical self-) contradictions, paradoxes, or basic complementarities of reasoning in theory formation or modeling. This may be done when constructing a kind of Gödelian meta-system or supranatural belief system. *Mode* 2 transdisciplinarity is needed if contextually robust, experiential knowledge (or wisdom), and understanding are to be integrated and related for providing (socio-technological) robust orientations or even solutions for complex, societally relevant problems (see Fig. 1).
3. A theory of *transdisciplinarity* includes *ontology*, *epistemology,* and *methodology*. The ontological examination describes the nature of an ill-defined real-world problem. The *epistemological* analysis describes what type of new knowledge and "orientation" will be provided or created based on what assumptions and means. The *methodology* offers (a system of) methods that may be applied to facilitate the process and to generate new knowledge.
4. In Mode II transdisciplinarity, we may distinguish between *transdisciplinary processes* and *transdisciplinary research*. The process facilitates the integration of knowledge between science- and practice-based epistemics and calls for a proper means of organization and methods.
5. There are different types of knowledge integration. Transdisciplinary projects need methods to integrate different types of epistemics such as knowledge from different disciplines (*interdisciplinarity*), perspectives and interests from different stakeholders (analytic mediation), knowledge from different subsystems and layers of a problem (holism), modes of thought (analytic vs. intuitive thinking), and intercultural integration (Fig. 4).

We may rely on more than two decades of practical experience in a wide range of transdisciplinary processes on transitions of urban and regional systems, organizations and policy processes as well as on first insights of learning by relating different cultures. Based on a record of more than 41 mid- and large-scale transdisciplinary projects, which were conducted with members of the ITdNet, as well as similar approaches carried out by private institutes such as the ISOE, we may suggest the following propositions referring to the practice of transdisciplinarity. ISOE is one of the private environmental, interdisciplinary knowledge institutes at the interface between (and with the aspiration of) independent academic research, multi-stakeholder moderation, and consultancy.

6. *The facilitation of transdisciplinary processes* (see Scholz and Steiner 2015; Fig. 1) *calls for professional management capabilities*. This includes assistance in avoiding errors in the initiation and planning phases, as they are the most expensive ones, focusing on the right issues/themes (i.e., defining the proper guiding question), and carefully assessing the outcomes of the process, following backward planning and concentrating only on those activities that are necessary for goal attainment (see Fig. 4). Facilitation calls for the support of contents as well as of the discourse and may become professionalized. A facilitator (perhaps a kind of "transdisciplinarity champion" [see Miah et al. 2015]) has to best meet the needs of practice and science and facilitate both the contents and the process.
7. *Transdisciplinary processes demand a set of specific challenges that go beyond normal project management*. Co-leadership on all levels may be most easily and efficiently operationalized by a double-winged organizational chart (see Scholz et al. 2006; Binder et al. 2015). The building of a protected discourse arena, the exclusion of day-to-day political issues, the definition of roles and functions of the participants, negotiating the goals of the project, and emergency management may be discussed or even written down, for instance, in a special brochure for all participants (see, e.g., Eilittä 2011). For acknowledging the ill-defined nature and inductive nature of transdisciplinary projects, there are trade-offs between backward planning (starting with anticipating how a process of synthesis might look like at the very beginning) and the flexible adaptation of the process to new insights and imponderabilities.
8. *The quality of a transdisciplinary process depends on the capacity and willingness of the participants and on proper methods of knowledge integration*. Knowledge integration and mutual learning become real if (a) the participants have the right knowledge, (b) are willing to participate and to follow the philosophy of mutual learning, and (c) if the right methods for framing and supporting these processes are available.
9. *The novelty of transdisciplinary processes induces multiple vulnerabilities*. The allocation of rights and responsibilities in an open, co-led process calls for mutual financing and shared liability with respect to claims of a large number of stakeholders, scientists, and other people concerned. Often, sensitive data become accessible and must be handles confidentially. All this is possible only if there are unambiguous, trustworthy, and balanced bonds among strong co-leaders from science and practice on all levels and subprojects of the project. The embedding of hybrid transdisciplinary processes that include knowledge transfer, mutual learning among science and practice, research, and multiple forms of education and on-the-job training in public knowledge institutions calls for special attention. The institutionalization of transdisciplinarity laboratories or transdisciplinarity colleges that run educational projects based on transdisciplinary processes may be seen as a prerequisite for developing high-quality transdisciplinary research in the long run.

The assessment of transdisciplinary processes calls for innovative forms of quantitative and qualitative appraisal and validation. An appraisal has to incorporate whether (i) the right issue has been focused on, (ii) proper perspectives and goals have been set, (iii) sufficient knowledge from practice and science can be incorporated, and (iv) whether the study has impacts on capacity building of science and practice and is promoting the intended transition of the system of interest. We argue that an evaluation of transdisciplinarity should not be done by a sloppy, ad hoc assemblage of evaluation criteria (and conventional means such as counting events, different types of publication, etc.). We suggest that assessments should rather be based on a theoretical conception that allows both to properly acknowledge the fundamental processes of acquiring, processing, and integrating knowledge both in Mode 1 and Mode 2 transdisciplinarity. The validation of newly produced knowledge, decisions, actions, and impacts of a specific transdisciplinary process on science and society has to go beyond face validation. There are not many theories around that can meet these aspirations. However, we suggest that Brunswik's theory of probabilistic functionalism may serve as a good starting point, as it conceptualizes the learning and adaptation of human action in complex human–environment systems under a functional, evolutionary perspective (see Scholz forthcoming; Scholz and Tietje 2002, Chap. 20).

As pointed out in both papers (Part I and Part II), transdisciplinarity is a demanding approach, particularly if applied factually in a real-world context. This also requires a reflection of traditional paradigms in science, the role of science in solving big societal challenges, and its relation to society and various stakeholder groups. In order to avoid its becoming a new, fuzzy buzz word, a thorough understanding of transdisciplinarity and the challenges, obstacles, and constraints related to its application must be part of a rigorous scientific and method-based process design that enables mutual learning between science and society that takes place at the same eye level but does not neglect the specific roles, functions, and responsibilities of science. To deal with the obstacles, barriers, and complexity of transdisciplinary processes is sometimes painful. But transdisciplinarity is also extremely rewarding—personally and societally. This is reflected by feedback from almost all practice partners, but also from senior scientists who have noticed the limits of disciplinary and usual interdisciplinary research in the context of transdisciplinary transformation.

References

Anonymous Referee #2 (2014) Interactive comment on "Recent revisions of phosphate rock reserves and resources: reassuring or misleading? An in-depth literature review of global estimates of phosphate rock reserves and resources" by J. D. Edixhoven et al. Earth Syst Dyn Discuss 4:C575–C598

Aronsson M (2002) Stadsförbättring Hamnen Malmö. University of Göteborg, Kandidatuppsats i Kulturgeografi, Götheborg

Baron RM, Kenny DA (1986) The moderator mediator variable distinction in social psychological-research—conceptual, strategic, and statistical considerations. J Pers Soc Psychol 51(6):1173–1182

Barondess JA (1996) Medicine against society—lessons from the Third Reich. JAMA 276(20):1657–1661

Binder CR, Hofer C, Wiek A, Scholz RW (2004) Transition towards improved regional wood flows by integrating material flux analysis and agent analysis: the case of Appenzell Ausserrhoden, Switzerland. Ecol Econ 49(1):1–17

Binder CR, Absenger-Helmli I, Schilling T (2015) The reality of rransdisciplinarity: a framework-based self-reflection from science and practice leaders. Sustain Sci. doi:10.1007/s11625-015-0328-2

Bunders JFG, Broerse JEW, Keil F, Pohl C, Scholz RW, Zweekhorst MBM (2010) How can transdisciplinary research contribute to knowledge democracy? In: Knowledge democracy, Springer, Berlin, pp 125–152

Cook PJ (2014) Interactive comment on "Recent revisions of phosphate rock reserves and resources: reassuring or misleading? An in-depth literature review of global estimates of phosphate rock reserves and resources" by J. D. Edixhoven et al. Earth Syst Dyn Discuss 4:C683–C685

Daston L (1992) Objectivity and the escape from perspective. Soc Stud Sci 22(4):597–618

Edixhoven JD, Gupta J, Savenije HHG (2013) Recent revisions of phosphate rock reserves and resources: reassuring or misleading? An in-depth literature review of global estimates of phosphate rock reserves and resources. Earth Syst Dyn Discuss 4:1005–1034

Edixhoven JD, Gupta J, Savenije HHG (2014) Recent revisions of phosphate rock reserves and resources: a critique. Earth Syst Dyn 5:491–507

Eilittä M (2011) The global TraPs project. In: Transdisciplinary processes for sustainable phosphorus management (2010–2015). Multi-stakeholder forum to guide and optimize P use. ETH-NSSI and IFDC, Zurich and Muscle Shoals

Fisher R, Ury W (1981) Getting to yes: negotiating agreement without giving in. Houghton Mifflin, Boston

Gibbons M, Nowotny H (2001) The potential of transdisciplinarity. In: Thompson Klein J, Grossenbacher-Mansuy W, Häberli R, Bill A, Scholz RW, Welti M (eds) Transdisciplinarity: Joint problem solving among science, technology, and society. An effective way for managing complexity. Birkhäuser, Basel, pp 67–80

Guinée JB (2002) Handbook of life cycle assessment: operational guide to the ISO standards. Kluwer, Dordrecht

Günther S (2004) Sustainable tourism development on La Digue Island, Republic of Seychelles. Transdisciplinary methods for sustainable solutions in a tropical paradise. Unpublished Diploma Thesis, ETH Zurich, Zurich

Habermas J (1996) Contributions to a discourse theory of law and democracy (trans: Regh W). MIT Press, Cambridge

Hilton J (2014) Interactive comment on "Recent revisions of phosphate rock reserves and resources: reassuring or misleading? An in-depth literature review of global estimates of phosphate rock reserves and resources" by J. D. Edixhoven et al. Earth Syst Dyn Discuss 4:EC686–EC686

Huang DB, Scholz RW, Gujer W, Chitwood DE, Loukopoulos P, Schertenleib R et al (2007) Discrete event simulation for exploring strategies: an urban water management case. Environ Sci Technol 41(3):915–921

ITdNet (2014) International transdisciplinarity network. Retrieved November 11, 2014

Jahn T, Bergmann M, Keil F (2012) Transdisciplinarity: between mainstreaming and marginalization. Ecol Econ 79:1–10

Jantsch E (1970) Inter- and transdisciplinary university: a systems approach to education and innovation. Policy Sci 1:403–428

Jasanoff S (1996) Beyond epistemology: relativism and engagement in the politics of science. Soc Stud Sci 26:393–418

Junker B, Flüeler T, Stauffacher M, Scholz RW (2008) Description of the safety case for long-term disposal of radioactive waste—the iterative safety analysis approach as utilized in Switzerland (technical paper as part of the project: "Long-term dimension of radioactive waste disposal: the role of the time dimension for risk perception"). ETH Zürich, Zurich

Karelaia N, Hogarth RM (2008) Determinants of linear judgment: a meta-analysis of lens model studies. Psychol Bull 134(3): 404–426

Klein JT (2008) Evaluation of interdisciplinary and transdisciplinary research. A literature review. Am J Prev Med 35:S116–S123

Krementsov NN (2006) Big revolution, little revolution: science and politics in Bolshevik Russia. Social Res 73(4):1173–1204

Kruetli P, Stauffacher M, Pedolin D, Moser C, Scholz RW (2012) The process matters: fairness in repository siting for nuclear waste. Soc Justice Res 25(1):79–101

Krutli P, Flueler T, Stauffacher M, Wiek A, Scholz RW (2010) Technical safety vs. public involvement? A case study on the unrealized project for the disposal of nuclear waste at Wellenberg (Switzerland). J Integr Environ Sci 7(3):229–244

Kuznick PJ (1987) Beyond the laboratory: scientists as political activists in 1930s America. University of Chicago Press, Chicago

Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P et al (2012) Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain Sci 7:25–43

Leydesdorff L, Ward J (2005) Science shops: a kaleidoscope of science-society collaborations in Europe. Public Underst Sci 14(4):353–372

Merton RK (1996) On social structure and science. Edited and with an introduction by Piotr Sztompka. University of Chicago Press, Chicago

Miah J, Griffiths A, McNeill R, Poonaji I, Martin R, Morse S et al (2015) A small scale transdisciplinary process to maximising the energy efficiency of food factories: insights and

recommendations from the development of a novel heat integration framework. Sustain Sci. doi:10.1007/s11625-015-0331-7
Moser C, Stauffacher M, Kruetli P, Scholz RW (2012a) The crucial role of nomothetic and idiographic conceptions of time: interdisciplinary collaboration in nuclear waste management. Risk Anal 32(1):138–154
Moser C, Stauffacher M, Kruetli P, Scholz RW (2012b) The influence of linear and cyclical temporal representations on risk perception of nuclear waste: an experimental study. J Risk Res 15(5):459–476
Moser C, Stauffacher M, Smieszek T, Seidl R, Kruetli P, Scholz RW (2013) Psychological factors in discounting negative impacts of nuclear waste. J Environ Psychol 35:121–131
Nicolescu B (2006) Transdisciplinarity: past, present and future. In: Haverkort B, Reijntjes C (eds) Moving Worldviews—Reshaping sciences, policies and practices for endogenous sustainable development, COMPAS Editions, vol 142–166, pp 142–166
Nicolescu B (2014) From modernity to cosmodernity. State University of New York Press, New York
Njoroge R, Birech R, Korir M, Mutisya M, Scholz RW (2015) Transdisciplinary processes of developing, applying, and evaluating a method for improving smallholder farmers' access to (phosphorus) fertilizers: The SMAP method. Sustain Sci
Pohl C, Rist S, Zimmermann A, Fry P, Gurung GS, Schneider F et al (2010) Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. Sci Public Policy 37(4):267–281
Posch A, Steiner G, Risopoulos F (2005) Die Erzherzog-Johann-Fallstudie: ein inter-und transdisziplinäres Lehr-und Forschungsprojekt der Kulturlandschaftsforschung; (Nachhaltigkeit durch Innovation-Entwicklungspotenzial einer Bergbaufolgelandschaft). Bundesministerium f. Bildung, Wissenschaft und Kultur, Wien
Preacher JK, Hayes AF (2004) SPSS and SAS procedures for estimating indirect effects in simple mediation models. Behav Res Methods Instrum Comput 36(4):717–731
Reed MS, Graves A, Dandy N, Posthumus H, Hubacek K, Morris J et al (2009) Who's in and why? A typology of stakeholder analysis methods for natural resource management. J Environ Manag 90(5):1933–1949
Schaltegger S, Beckmann M, Hansen EG (2013) Transdisciplinarity in corporate sustainability: mapping the field. Bus Strateg Environ 22(4):219–229
Schneidewind U, Scheck H (2013) Die Stadt als „Reallabor" für Systeminnovationen. In: Rückert-John J (ed) Soziale Innovation und Nachhaltigkeit. Perspektiven sozialen Wandels. Springer VS, Wiesbaden, pp 229–248
Scholz RW (2000) Mutual learning as a basic principle of transdisciplinarity. In: Scholz RW, Häberli R, Bill A, Welti W (eds) Transdisciplinarity: Joint problem-solving among science, technology and society. Workbook II: Mutual learning sessions. Haffmans Sachbuch, Zürich, pp 13–17
Scholz RW (2011) Environmental literacy in science and society: from knowledge to decisions. Cambridge University Press, Cambridge
Scholz RW (2012) Transdisziplinäre Krebsforschung mit den Mayas. Das Macocc Projekt—Body-Mind Komplementaritäten auf der Ebene der Zelle, des Patienten und der therapeutischen Allianz. EANU Spec 7:1–38
Scholz RW (forthcoming). From visual perception to sustainable transition management: Egon Brunswik's theory of probabilistic functionalism
Scholz RW, Marks D (2001) Learning about transdisciplinarity: where are we? Where have we been? Where should we go? In: Klein JT, Grossenbacher-Mansuy W, Häberli R, Bill A, Scholz RW, Welti M (eds) Transdisciplinarity: Joint problem solving among science, technology, and society. Birkhäuser Verlag AG, Basel, pp 236–252
Scholz RW, Stauffacher M (2007) Managing transition in clusters: area development negotiations as a tool for sustaining traditional industries in a Swiss prealpine region. Environ Plan A 39(10):2518–2539
Scholz RW, Stauffacher M (2009) From a science for society to a science with society. Psychologische Rundschau 60(4):242–U280
Scholz RW, Steiner G (2015) The real type and ideal type of transdisciplinary processes: part I—theoretical foundations. Sust Sci. doi:10.1007/s11625-015-0326-4
Scholz RW, Tietje O (2002) Embedded case study methods: integrating quantitative and qualitative knowledge. Sage, Thousand Oaks
Scholz RW, Wellmer F-W (2013) Approaching a dynamic view on the availability of mineral resources: what we may learn from the case of phosphorus? Glob Environ Change 23:11–27
Scholz RW, Wellmer F-W (2014)Comment on: "Recent revisions of phosphate rock reserves and resources: a critique" by Edixhoven et al. (2014)–phosphate reserves and resources: what conceptions and data do stakeholders need for sustainable action? Earth Syst Dyn Discuss 5(5): 1–49
Scholz RW, Bösch S, Koller T, Mieg HA, Stünzi J (eds) (1996) Industriereal Sulzer-Escher Wyss: Umwelt und Bauen—Wertschöpfung durch Umnutzung (ETH-UNS Fallstudie 1995) [Industrial area Sulzer-Escher Wyss: environment and construction—value added through re-use (ETH-UNS case study 1995)]. vdf, Zurich
Scholz RW, Bösch S, Stauffacher M, Oswald J (eds) (2001) Zukunft Schiene Schweiz 1: Ökoeffizientes Handeln der SBB. ETH-UNS Fallstudie 1999 [Future of railway systems 1: ecoefficient acting of the Swiss Railway Company. ETH-UNS Case Study 1999. Rüegger, Zurich
Scholz RW, Stauffacher M, Bösch S, Wiek A (eds) (2002) Landschaftsnutzung für die Zukunft: der Fall Appenzell Ausserrhoden (ETH-UNS Fallstudie 2001) [Utilisation of landscape for the future: the case of Appenzell Ausserrhoden (ETH-UNS case study 2001)]. Rüegger und Pabst, Zurich
Scholz RW, Stauffacher M, Bösch S, Krütli P (eds) (2003) Appenzell Ausserrhoden Umwelt Wirtschaft Region. ETH-UNS Fallstudie 2002 [environment economy region. ETH-UNS case study 2002]. Rüegger und Pabst, Zurich
Scholz RW, Lang DJ, Wiek A, Walter AI, Stauffacher M (2006) Transdisciplinary case studies as a means of sustainability learning: historical framework and theory. Int J Sustain High Educ 7(3):226–251
Scholz RW, Stauffacher M, Bösch S, Krütli P, Wiek A (eds) (2007) Entscheidungsprozesse Wellenberg - Lagerung radioaktiver Abfälle in der Schweiz (ETH-UNS Fallstudie 2006) [Decision processes Wellenberg—repository of radioactive waste in Switzerland (ETH-UNS case study 2006]. Rüegger, Zurich
Scholz RW, Ulrich AE, Eilittä M, Roy AH (2013) Sustainable use of phosphorus: a finite resource. Sci Tot Environ 461:799–803
Scholz RW, Roy AH, Brand FS, Hellums DT, Ulrich AE (eds) (2014a) Sustainable phosphorus management: a global transdisciplinary roadmap. Springer, Berlin
Scholz RW, Roy AH, Hellums DT (2014b) Sustainable phosphorus management. A transdisciplinary challenge. In: Scholz RW, Roy AH, Brand FS, Hellums DT, Ulrich AE (eds) Sustainable phosphorus management. A sustainable roadmap. Springer, Berlin, pp 1–128
Schori S, Krütli M, Stauffacher M, Flüeler T, Scholz RW (2009) Siting of nuclear waste repositories in Switzerland and Sweden. Stakeholder preferences for the interplay between technical

expertise and social input. ETH-NSSI case study 2008. ETH, Zurich
Seidl R, Brand F, Stauffacher M, Krütli P, Le QB, Spörri A et al (2013) Science with society in the anthropocene. Ambio 42(1):5–12
Stauffacher M, Flueeler T, Krueli P, Scholz RW (2008) Analytic and dynamic approach to collaboration: a transdisciplinary case study on sustainable landscape development in a Swiss prealpine region. Syst Pract Action Res 21(6):409–422
Stephens JC, Hernandez ME, Roman M, Graham AC, Scholz RW (2008) Higher education as a change agent for sustainability in different cultures and contexts. Int J Sustain High Educ 9(3):317–338
Steiner G, Posch A (2006) Higher education for sustainability by means of transdisciplinary case studies: an innovative approach for solving complex, real-world problems. J Clean Prod 14:877–890
Stirling A (2008) "Opening up" and "Closing down"—power, participation, and pluralism in the social appraisal of technology. Sci Technol Hum Values 33(2):262–294
Stokols D, Hall KL, Taylor BK, Moser RP (2008) The science of team science—overview of the field and introduction to the supplement. Am J Prev Med 35(2):S77–S89
Susskind LE, McKearnen S, Thomas-Lamar J (1999) The consensus building handbook: a comprehensive guide to reaching agreement. Sage Publications, Thousand Oaks
van Breda J, Musango JK, Brent AC (in press) Undertaking individual transdisciplinary PhD research for sustainable development: case studies from South Africa. Int J Sustain High Educ
Vilsmaier U, Engbers M, Luthardt P, Maas-Deipenbrock R-M, Wunderlich S, Scholz RW (2015) Case based mutual learning sessions: knowledge integration and transfer in transdisciplinary processes. Sustain Sci. doi:10.1007/s11625-015-0335-3
Walter AI, Helgenberger S, Wiek A, Scholz RW (2007) Measuring societal effects of transdisciplinary research projects: design and application of an evaluation method. Eval Program Plan 30:325–338
Wickson F, Carew AL, Russell AW (2006) Transdisciplinary research: characteristics, quandaries and quality. Futures 38(9):1046–1059
Wiek A (2007) Challenges of transdisciplinary research as interactive knowledge generation—experiences from transdisciplinary case study research. Gaia-Ecol Perspect Sci Soc 16(1):52–57
Wiek A, Walter AI (2009) A transdisciplinary approach for formalized integrated planning and decision-making in complex systems. Eur J Oper Res 197(1):360–370
Zscheischler J, Rogga S (2015) Transdisciplinarity in land use science—a review of concepts, empirical findings and current practices. Futures 65:28–44