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Research

Characteristics, emerging needs, and challenges of transdisciplinary sustainability science: experiences from the German Social-Ecological Research Program

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ABSTRACT. Transdisciplinary sustainability science (TSS) is a prominent way of scientifically contributing to the solution of sustainability problems. Little is known, however, about the practice of scientists in TSS, especially those early in their career. Our objectives were to identify these practices and to outline the needs and challenges for early career scientists in TSS. To that end, we compiled 10 key characteristics of TSS based on a literature survey. We then analyzed research groups with 81 early career scientists against these characteristics. All of these research groups are funded by an ongoing federally funded German program for social-ecological research whose main feature is to promote sustainability-oriented inter- and transdisciplinary research. We found that the practices of the 12 groups generally correspond with the characteristics for TSS, although there is ample variation in how they were addressed. Three major challenges were identified: (1) TSS demands openness to a plurality of research designs, theories, and methods, while also requiring shared, explicit, and recursive use of TSS characteristics; (2) researchers in TSS teams must make decisions about trade-offs between achievements of societal and scientific impact, acknowledging that focusing on the time-consuming former aspect is difficult to integrate into a scientific career path; and (3) although generalist researchers are increasingly becoming involved in such TSS research projects, supporting the integration of social, natural, and engineering sciences, specialized knowledge is also required.

Key Words: *early career scientists; interdisciplinarity; research practice; self-evaluation; social-ecological research; sustainability science; trandisciplinarity*

INTRODUCTION

Since the late 1980s, sustainability science has been emerging as a productive field of scientific inquiry. Characterized by an inclusive approach to the study of the dynamic relationship between society and nature, it spans across local, regional, and global scales (Kates et al. 2001, Komiyama and Takeuchi 2006, Bettencourt and Kaur 2011). There are different understandings of what sustainability science actually entails and how to differentiate it from other forms of environment-oriented knowledge production. These differences are often related to the disciplinary foundations of the scholars involved. For instance, these foundations can be ecological as in the social-ecological resilience school (Holling 2001), geographical as in landscape ecology (Wu 2013), or sociological as in the Frankfurt school of "societal relations to nature" (Becker and Jahn 2006).

One encounters a variety of terminology and definitions in sustainability research. A central point among these and many other approaches is that sustainability science contributes scientific-based solutions to sustainability problems through interdisciplinary research that integrates science and society. Examples of sustainability problems include combating overfishing, biodiversity loss, or climate change. In contrast to disciplinary perspectives on the study of sustainability (mode-1 science, see Spangenberg 2011), mode-2 sustainability science is performed in inter- and transdisciplinary ways (Schneidewind and Augenstein 2012, Huber et al. 2013). We name this kind of science transdisciplinary sustainability science (TSS). TSS integrates different disciplinary knowledge as well as scientific and nonscientific knowledge (Gibbons 1999, Nowotny et al. 2001, Buizer et al. 2011). While TSS is appropriate to address many real-world sustainability problems, there is increasing complexity in communicating and coordinating TSS (Cundill et al. 2005, Pade-Khene et al. 2013). This is of particular concern for early career scientists, who need to develop viable career paths.

In Germany, TSS expanded substantially in 1999, when the German Federal Ministry of Education and Research (BMBF) initiated a funding scheme for social-ecological research (SÖF program). This program is inter- and transdisciplinary at its core. The SÖF program ran in two waves, with the second phase (2008–2014) being integrated in Germany's overarching Research Program for Sustainable Development (FONA). Today, the SÖF program plays an important role in the German government's Strategy for Sustainability (DLR 2007, Müller 2013). The SÖF approach is largely congruent with TSS because it investigates sustainability problems to generate practical solutions for real-world problems while producing scientific knowledge on the foundation, explanation, and solution of a given sustainability issue (Jahn 2002).

Within the SÖF program, one funding scheme specifically supports the establishment of early career research groups. Since 2001, SÖF funded 21 early career groups, costing approximately € 37 million (Müller 2013). The aim of the establishment of early

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Table 1. Overview of the 12 social-ecological research groups funded within the Program for Social-Ecological Research in Germany, 2008–2014.

Project number	Project name	Guiding questions (main problem focus)	Number of scientific team members (male/female); leader of group's gender	Key publications (scientific and practice oriented)	Project website
1	Chameleon	What are the barriers and promoters for adapting utilities to climate change?	2/4; male	Eisenack and Stecker (2012), Eisenack et al. (2014), Pechan and Eisenack (2014)	http://www.climate-chameleon.de
2	GETIDOS	Why and how can social entrepreneurship offer sustainable approaches in the water sector?	2/5; male	Ziegler (2010), Partzsch and Ziegler (2011), Ziegler et al. (2014)	http://www.getidos.net
3	Ecosystem Services	How can cultural landscapes be managed for ecosystem services?	4/3; male	Plieninger et al. (2012, 2013), Bieling et al. (2014)	http://www.ecosystemservices.de
4	Besatzfisch (Stocking Fish)	Under what conditions is fish stocking sustainable?	5/2; male	van Poorten et al. (2011), FAO (2012), Hühn et al. (2014)	http://www.besatz-fisch.de
5	Fair Fuels	How can global biofuel trade be regulated toward sustainability?	4/4; male	Brüntrup et al. (2010), Dunkelberg et al. (2014), Backhouse (2015)	http://www.fair-fuels.de
6	CIVILand	How can land-use conflicts be solved using financial incentives?	3/4; female	Schomers and Matzdorf (2013), Matzdorf and Meyer (2014), Matzdorf et al. (2014)	http://www.civiland-zalf.org
7	PoNa	How do different policies in the fields of rural development and agro-biotechnology shape the societal relations to nature (un)sustainably?	1/5; 2 female	Gottschlich et al. (2014), Mölders (2014), Gottschlich and Mölders (2015)	http://www.pona.eu
8	EE-Regionen (Renewable Energy Regions)	How can renewable energy self-sufficiency be achieved sustainably?	5/2; female	Hauber and Ruppert-Winkel (2012), Ruppert-Winkel et al. (2013, 2014)	http://www.ee-regionen.de
9	plan B:altic	How can urban and regional planning deal with climate change impacts?	3/4; female	Albers and Deppisch (2012), Deppisch and Hasibovic (2013), Beichler et al. (2014)	http://www.planbaltic.hcu-hamburg.de
10	BioDiva	How can genetic erosion of agrobiodiversity in rice-paddy systems be halted?	3/6; female	Christinck and Padmanabhan (2013), Betz et al. (2014), Nagabhatla et al. (2015)	http://www.uni-passau.de/en/biodiva
11	Innovation in Governance	How can innovation processes in governance be shaped for sustainable development?	3/1; male	Amelung (2012), Mann and Absher (2014), Voß and Simons (2014)	http://www.innovation-in-governance.org
12	Biofuel as Social Fuel	To what extent does the production and use of biofuels coincide with the concept of sustainability in all of its dimensions?	1/5; female	Kaup and Selbmann (2013), Venghaus and Selbmann (2014), Selbmann (2015)	http://www.kooperation-international.de/detail/info/verbundprojekt-biofuel-as-social-fuel-biokraftstoffe-als-sozialer-treibstoff-einer-nachhaltigen-en.html

career research groups is to promote scientific qualification in TSS (e.g., through Ph. D. projects). In particular, the program targets are to strengthen social-ecological research in Germany, to promote the skills of early career researchers to manage inter- and transdisciplinary research projects, and to strengthen cross-linkages between scientists inside and outside academia (Müller 2013).

Although TSS research practices and outcomes are increasingly being studied (e.g., Cundill et al. 2005, Tötzer et al. 2011, Beland Lindahl and Westholm 2014, Mattor et al. 2014), the German SÖF context has only been marginally explored (e.g., Nölting et al. 2004, Luks and Siebenhüner 2007). We aim to fill this gap by analyzing the various practices of the 12 early career research groups within the second phase of SÖF, which comprised 81 early career scientists (Table 1). Our first objective is to contrast the research approaches used by the 12 groups as a sample of ongoing TSS in Germany. Our second objective is to derive conclusions regarding the needs and challenges of TSS from the perspective of early career scientists. We address the following research questions: Are the characteristics of TSS relevant in the research practice of the analyzed early career research groups and if so, in what ways? What shared needs and challenges arise for early career scientists in the practice of TSS?

METHODS

We used an "ex post" self-evaluation approach after the projects were completed. Self-evaluation is an established method for describing and evaluating research projects (Defila and Di Giulio 1999, DeGEval 2004, Bergmann et al. 2005). It involves a systematic, data-based procedure of description and assessment in which the people evaluating are the same ones who completed the activities evaluated (Stockmann and Meyer 2014). The set of evaluation criteria must be transparent, feasible, and flexible, depending on the goals of the evaluation (Defila and Di Giulio 1999, Klein 2008, Wolf et al. 2013). Evaluation principles, characteristics, and criteria have been specifically proposed for TSS (Defila and Di Giulio 1999, Bergmann et al. 2005, Pohl and Hirsch Hadorn 2006, Wickson et al. 2006, Klein 2008, Lang et al. 2012).

Our interest was to analyze research practices systematically to identify the shared needs and challenges for early career scientists conducting TSS. Hence, our self-evaluation deviated from traditional evaluation approaches designed to judge "poor" and "good" performance. We first developed an analytical framework by deducing TSS characteristics. This was based on sustainability science literature and seven key documents addressing the goals and criteria of the German SÖF program (Bundesministerium für Bildung und Forschung 2000, Balzer and Wächter 2002, Jahn 2002, 2005, DLR 2007, Luks and Siebenhüner 2007, EvaConsult 2012). The initial set of characteristics for describing the research projects was further refined in discussions with the leaders of the research groups, who are also the authors of this article. Through this process, we identified 10 characteristics for TSS. We then grouped these into three dimensions: framing, implementation, and outcome (see *Analytical Framework: Characteristics of Transdisciplinary Sustainability Science*).

The research group leaders conducted the subsequent analysis. This was done in a three-step process: a questionnaire was developed by operationalizing the 10 TSS characteristics, data were collected through the questionnaire, and data were discussed and interpreted in a workshop setting.

Questionnaire development

Our questionnaire (Appendix 1) was inspired by previous evaluation approaches for transdisciplinary projects (especially Defila and Di Giulio 1999, Bergmann et al. 2005). The questionnaire included short definitions of technical terms and provided the literature on which the 10 TSS characteristics were based. Because the TSS characteristics are often closely related to each other, the answer to a given question sometimes provided important information for several characteristics of TSS.

Data collection

The questionnaire was e-mailed to and fully answered by all 12 research group leaders. The group leaders decided on their own if they wanted to integrate other team members of their group into this process. Answers were summarized in tables and in a draft paper that described first results in a standardized manner. These findings were cross-checked by the group leaders, and adjustments were made as needed to represent the original meaning. Although we used a written inquiry, our study had the character of a qualitative approach. We mostly used open-ended questions and gave opportunities to elaborate on answers further upon request and in face-to-face or online discussion among the group leaders.

Interpretation of results

As a last step, we organized a one-day workshop with the group leaders, facilitating a self-evaluative group discussion and interpretation of the questionnaire's results. The participants prepared for the group discussion by studying the assembled results and reflecting upon them against the background of their specific experiences. The main focus of the workshop was to identify shared needs for early career scientists in TSS and to discuss related challenges. Subsequently, preliminary results were reworked and key issues for the paper were identified. This continued via online discussions while we worked on the paper.

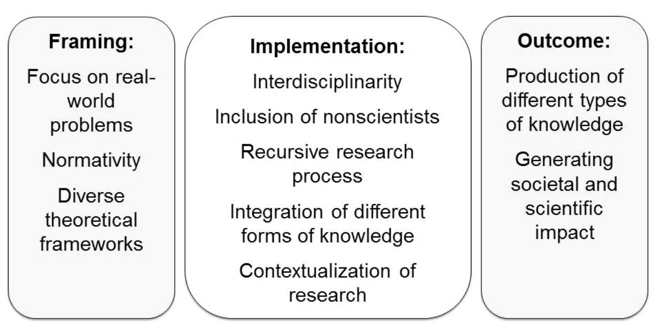
To achieve our objectives, we used the group leaders' insider knowledge. This gave us the opportunity to tap into the real-life expertise and experience of those actively working in the field. This provided hands-on knowledge and results that were otherwise potentially hidden. The diverse set of group leaders was thus able to consider the results based on in-depth expertise of facts and processes. A trustful atmosphere among the group leaders, who had met regularly since the start of their funding period, enabled an open and critical exchange, supported by data from the questionnaire.

Our self-evaluation was not intended to measure the success of the projects but rather to derive shared needs and challenges in relation to TSS. This important issue relativizes the most critical aspect of our self-evaluation process: our inability to be impartial. For instance, group leaders might have the incentive to show their projects in the best light by not sharing those aspects that did not go well during their projects. Consequently, a critical reflection of our own approach and action is important (DeGEval 2004). We did so during the workshop and the online discussions afterwards. Moreover, we avoided comparing the success of the projects.

ANALYTICAL FRAMEWORK: CHARACTERISTICS OF TRANSDISCIPLINARY SUSTAINABILITY SCIENCE

Based on a literature review and discussions among the research group leaders, we identified the following properties as important characterizing features of the SÖF program and TSS in general: (1) focus on real-world problems, (2) normativity, (3) diverse theoretical frameworks, (4) interdisciplinarity, (5) inclusion of nonscientists, (6) recursive research process, (7) integration of different forms of knowledge, (8) contextualization of research, (9) production of different types of knowledge, and (10) generation of societal and scientific impact. We bundle these characteristics according to three dimensions: framing, implementation, and outcome (Fig. 1).

Fig. 1. Characteristics of transdisciplinary sustainability science, with a focus on the German Program for Social-Ecological Research.



Framing

(1) Focus on real-world problems
TSS typically engages in place-based and solution-oriented research (Kates et al. 2001). Its focus emerges from the real-world problems associated with sustainability challenges, which are discussed by or related to the public. Many sustainability challenges are often characterized as "wicked problems" with complex feedbacks and stakeholder coalitions (Rittel and Weber 1973). A central feature of TSS is the ability to frame an identified sustainability problem as a research issue or question that is amendable to scientific inquiry.

(2) Normativity
"Sustainable development" and "sustainability" are normative, contested concepts about how society should interact and deal with nature and natural resources so as to meet present and future aspirations. These ideas typically remain vague in public discussion (Jacobs 1999). Accordingly, TSS needs to spell out these notions concretely and to provide conceptions of sustainability that make the discussion precise and transparent (Ziegler and Ott 2011, Gottschlich 2015).

(3) Diverse theoretical frameworks
There is no general theory or all-encompassing research framework for TSS (Bettencourt and Kaur 2011). Rather, theories are drawn upon as they fit the respective problem. There are, however, several recent theoretical frameworks that are more widely used than others (Binder et al. 2013). Among the most well known internationally are the frameworks of social-ecological resilience (Holling 2001, Folke et al. 2010) and social-ecological systems (Ostrom 2007). In Germany, a specific concept of societal relations to nature (Becker and Jahn 2006) was initially framed around the SÖF program.

Implementation

(4) Interdisciplinarity
Interdisciplinarity means the cooperation of scientists from different disciplines with the objective to answer common research questions at the margins or beyond traditional disciplines (Defila and Di Giulio 1999, Weingart 2000). Most typologies distinguish between multidisciplinary as a conglomeration of disciplinary components, and interdisciplinarity as a "synthetic attempt of mutual interaction" (Huutoniemi et al. 2010). Further categorizations can be made in terms of degrees of disciplinary integration, interdisciplinary practices, and underlying rationales (Huutoniemi et al. 2010).

(5) Inclusion of nonscientists
TSS involves nonscientists in knowledge production (Funtowicz and Ravetz 1993, Jahn et al. 2012). Krütli et al. (2010) differentiate four intensities of nonscientific involvement: information (one-way communication), consultation (one-way communication but including the consideration of responses), collaboration (nonscientists collaborate with scientists and can influence the outcome), and empowerment (authority is given to nonscientists by giving them rights to decide on the course of the research in which they are involved). Defila et al. (2006) differentiate three varieties of transdisciplinary involvement for external participants according to continuity: punctual involvement, but with a substantial contribution for achieving the objectives of the projects; involvement over a long time period; and the whole project time on equal footing as scientific partners (similar to empowerment).

(6) Recursive research process
The TSS research process can be organized along three phases (Jahn et al. 2012, Lang et al. 2012, Brandt et al. 2013): collaborative problem framing, co-creation of solution-oriented and transferable knowledge, and integration and application of produced knowledge. Recursive loops in the research process allow for reflection on preliminary results, feedback from the partners of practice, revision of data interpretation, and further planning of research steps (Pohl and Hirsch Hadorn 2006).

(7) Integration of different forms of knowledge
TSS requires the integration of different forms of knowledge. This integration results from the interdisciplinary character, i.e., integration of knowledge from different disciplines, and from the inclusion of knowledge from nonscientists during the research process (Wiesmann et al. 2008; for other types of integration see Scholz 2011). Although several general methods and instruments are available to guide integration in TSS (e.g., McDonald et al. 2009, Bergmann et al. 2012), it is often necessary to adapt methods to the specific project goal and context.

(8) Contextualization of research
The contextualization of research within its social context is part of a more general trend in the co-evolution of science and society (Nowotny et al. 2001). TSS is responsive to context in a way that fundamentally differs from disciplinary science, and this raises its own epistemic challenges. In particular, the goal of providing relevant research results for partners from policy, civil society, or business is a driver for place-based knowledge production. The in-depth case study has been identified as a research design for producing practice-oriented knowledge in TSS (Krohn 2008). However, this does not necessarily result in general insights that hold across cases, the gold standard for hypothesis-testing, theory-generating science. This is a tension in TSS rather than a necessary dichotomy; case studies can be used for both deductive and inductive purposes (Flyvbjerg 2006).

Outcomes

(9) Production of different types of knowledge
TSS produces various kinds of knowledge, often distinguished into system, target, and transformation knowledge (Hirsch Hadorn et al. 2006). System knowledge aims at understanding and delineating a complex system along with its components and interrelations, i.e., grasping a complex problem of sustainability. Target knowledge (sometimes called orientation knowledge) describes and clarifies what sustainable situations regarding a certain issue should look like. Transformation knowledge provides insights on how to transform a given system toward the desired outcome, i.e., solving a sustainability problem.

(10) Generating societal and scientific impact
TSS typically aims to generate impact in both science and society (Jahn et al. 2012). The goal is to create "socially robust knowledge" that is valid in the real world and that moves us toward more sustainable processes and outcomes (Gibbons 1999, Scholz 2011). At the same time, TSS has to contribute to scientific progress. The classical ways of showing scientific excellence

Table 2. Problem definition strategies, normative goals, and theoretical frameworks of the 12 social-ecological research groups.

	Problem definition (main strategies of deducing the research problems)							
Project number[†]	Continuation of previous research line	Desk research of public policy documents	Discussions among researchers	Discussions with partners of practice	Evaluation of existing research	Stakeholder workshops	Normative goals	Theoretical overarching framework (s)
1	X	X		X	X	X	Different but not joint normative perspectives (e.g., reducing adverse impacts of climate change; effectiveness or efficiency of selected climate change adaptations)	Social-ecological systems; action framework of adaptation
2	X	X	X	X	X		The role of social entrepreneurship in the water sector for fostering human capabilities and strong sustainability	Strong sustainability with capabilities approach
3			X	X	X		Safe-guarding ecosystem services	Social-ecological resilience
4		X	X		X	X	Avoiding negative biodiversity impacts; maximizing social benefits associated with fish stocking	Social-ecological resilience; social-ecological systems
5			X	X	X		Ensuring ecologically and socially sound biofuel production	Societal relations to nature
6					X	X	Maintenance and improvement of ecosystem services	Social-ecological systems
7	X	X	X	X	X	X	Critical-emancipatory perspective on sustainable development (e.g., critique of domination, search for intra- and inter-generational justice)	Societal relations to nature; (re) productivity
8		X	X	X	X	X	Developing socially just and ecologically sound renewable energy regions	Social-ecological resilience
9		X	X	X	X		Social-ecological strategies to deal with climate change impacts on the collective resource space	Social-ecological resilience
10	X				X	X	Fostering sustainable and gender-equitable development	Social-ecological systems
11	X	X	X	X	X		Avoidance and prevention of systemic repercussions; embracing the complexities of social-ecological situations	Political ecology; science and technology studies
12		X		X	X	X	"Biofuel" as a synonym for social progress in the sense of global learning processes	Social-ecological systems; societal relations to nature

[†]See Table 1 for project descriptions.

related to mode-1 science (e.g., papers in high-impact journals) can be challenging for TSS researchers. This challenge has opened the ongoing debate for alternative measures of scientific impact (Ukowitz 2014).

RESULTS

Survey results: presence and configuration of transdisciplinary sustainability science characteristics in 12 early career research groups

Framing

(1) Focus on real-world problems: All of the research groups focused on solving real-world sustainability problems. The 12 groups showed a great variety of foci, including energy supply, climate change, ecosystem services, social entrepreneurship, and sustainable fisheries. There was also a diversity of actors involved (e.g., businesses and entrepreneurs, angling clubs, town administrations) and instruments focused on (e.g., payments for ecosystems services, reflection on governance instruments for sustainable development; Table 1). All 12 groups involved partners of practice in defining the problem, with 9 of 12 involving discussions with practitioners, and 7 of 12 involving stakeholder workshops (Table 2).

(2) Normativity: All groups explicitly endorsed sustainability as a normative goal to be advanced via the transdisciplinary research process (Table 2). However, there was a substantial difference among the research groups in how they conceptualized and operationalized the normative dimension of sustainability or sustainable development. For example, two groups worked out an explicit, ethical conception of sustainability: the GETIDOS project worked with a philosophical conception of "strong sustainability" that focuses on central human capabilities as an absolute standard of inter- and intra-generational justice and on nature as a nonsubstitutable human capital (Ziegler et al. 2014).

The PoNa project's scientific team developed a shared critical and emancipatory conception of sustainable development at the beginning of the research project (Friedrich et al. 2010).

A different route was chosen by the Besatzfisch project. Its normative frame used the legally defined objectives and criteria of sustainable fisheries as defined in state-specific fisheries legislation and national-level nature conservation law. This resulted in sustainability being mainly defined in ecological terms, but the participating angling clubs modified biological objectives in light of local social and economic conditions. Another approach is exemplified by the group Biofuel as Social Fuel, which conceptualized the normative dimension of sustainability together with the involved stakeholders. By contrast, the Chameleon group worked on sustainability without a shared conception of sustainability within the research group. Rather, the group leader allowed space for different normative perspectives to develop within the group.

(3) Diverse theoretical frameworks: We found a diversity of theoretical frameworks in the 12 groups analyzed, with a total of eight different overarching frameworks (Table 2). Three, however, were used most often: five groups used the social-ecological system analysis framework, four groups used the social-ecological resilience framework, and three used the societal relations to nature framework. Questionnaire responses reveal that the interdisciplinary composition of the research teams made it difficult to agree on a joint theoretical base. Five groups used more than one single overarching theoretical framework. Moreover, all 12 groups had more specific frameworks for sub-projects. Even groups using the same framework used it in different ways. For example, the framework of social-ecological resilience was used as a normative argument for sustainability with partners of practice in the case of EE-Regionen, or as the bridging concept to initiate and facilitate processes of interdisciplinary integration in the case of plan B:altic (Beichler et al. 2014).

Implementation

(4) Interdisciplinarity: Scientists from a wide variety of disciplinary backgrounds were involved in the 12 groups, including humanities and social science, natural and life sciences, and engineering (Table 3). In addition, scientists from hybrid disciplines were involved such as environmental studies, planning, and systems science. These hybrid disciplines are interdisciplinary from the outset, combining aspects of natural and social sciences. Social scientists were included in all 12 of the groups. Natural and life sciences such as physics and biology were represented in fewer numbers. Four of the groups included engineers. In 11 of the groups, there was at least one researcher representing a hybrid discipline. As stated in the questionnaire responses, the scientists from hybrid disciplines tended to contribute their social scientific knowledge to the teams in terms of perspectives and methods (e.g., forest scientists with socioeconomic qualitative methods in EE-Regionen; system scientist with methods of interpretative social science in Biofuel as Social Fuel).

(5) Inclusion of nonscientists: All of the research groups involved nonscientists in some form (see Table 2, column problem definition, and Table 3). A frequent project design included an early kick-off workshop or discussion with the respective partners of practice, followed by further involvement of nonscientists in the research phases via practice-oriented workshops to validate intermediary results and discuss the research project, leading to handbooks and publications oriented toward the general public. Our analysis shows that all groups engaged with their partners of practice up to an active collaboration phase (Table 3) and that no group only informed their nonacademic audience. However, within the project phase, none of the groups empowered their partners of practice in terms of delegating responsibility for research decisions.

The specific type of involvement for the partners of practice differed throughout the research processes. Two main different forms occurred. Most of the projects had the same partners of practice over the whole project (Table 3); these were usually a small number of partners such as municipalities, companies, and nongovernmental organizations. In contrast, three groups had changing partners depending on which issues were in focus, and they incorporated many stakeholders via regular consultations, networks, or workshops. For example, the group CIVILand fostered exchange among stakeholders from different countries by organizing two different transdisciplinary events: a German-British symposium and an U.S.-German world café.

(6) Recursive research process: Nine of the groups divided their research process into the three phases introduced above. Two of these nine groups formulated their own phases, which can be adjusted to the above ones. As stated in the questionnaire responses, while the forms of nonscientist involvement (see characteristic 5) were more or less similar in every phase in all of these groups, the type of knowledge generated (see characteristic 9) corresponded more specifically with the three phases. System knowledge was often generated in all three phases or at least in the first two, target knowledge was generated in the first and second phases, and transformation knowledge was mainly generated in the second and third phases.

The research groups showed a wide range of adaptations of topics, results, and research frameworks based on the partners of practice feedback, from small adjustments to practice-science collaboration that led to a product idea and its implementation and to the development of collaborative frameworks (Table 3). One example is plan B:altic's process of defining the research object. First, from an interdisciplinary academic standpoint, "urban region" was defined as the object of research. Through a transdisciplinary research process, this was then defined more concretely by referring to the core city and surrounding local communities (the so-called *Stadt-Umland-Raum*) up to the third circle. This was already an existing institutionalized category within planning, but did not yet have concrete practical cooperation among the communities.

(7) Integration of different forms of knowledge: The groups used a wide variety of ways to work together (Table 3). Five of the groups used bilateral cooperation, and seven of the groups gathered and analyzed joint data. One of the most common forms of interdisciplinary integration was joint publications, which was done by all 12 groups. Some of the groups also published together with their partners of practice. All of the groups held interdisciplinary workshops to integrate the various disciplines, as well as workshops with partners of practice. Three of the groups used modeling as a method of integration. Seven of the groups used joint case studies explicitly as a method of integration so that the different disciplinary perspectives on the research

Table 3. Implementation characteristics of the 12 social-ecological research groups.

Project number†	Disciplines involved‡	Inclusion of nonscientists	Same partners of practice over the whole project duration	Recursive research process	Integration of different forms of knowledge§	Contextualization of research: case study focus	International dimension of research|
1	EC, ENG, PHY, PO, SO	Information, consultation, collaboration	Yes	Partners of practice selected sub-topics, gave feedback	C, D, E, F, M, P, W	Regional, national scales	International events
2	CU, ENG, ENV, PHI, PO	Information, consultation, collaboration	Yes	Partners of practice gave feedback; practice-science collaboration led to product idea and implementation	C, D, P, W	Regional, national scales	Advisory board, case study, cooperation, international events, partners
3	AG, CU, EC, ENV, PO	Information, consultation, collaboration	Yes	Partners of practice gave feedback	B, F, P, T, W	Regional scale	Case study, cooperation, international events
4	AG, ED, ENV, LI, PY, SO, SY	Information, consultation, collaboration	Yes	Partners of practice selected experimental approach of fish stocking, helped interpret results, gave feedback	C, D, F, M, P, W	Regional scale	Advisory board, cooperation, international events, partners
5	AG, EC, ENG, PO, PS, SO	Information, consultation, collaboration	No	Partners of practice gave feedback	B, C, P, W	Regional scale	Case study, international events
6	AG, EC, GE, LA, PO, PS, SO	Consultation, collaboration	No	Selection of topics through online survey and workshop	C, D, P, W	National scale	Case study, cooperation, international events
7	EA, ENV, PO	Information, consultation, collaboration	Yes	Recursive development of frameworks; partners of practice gave feedback	B, D, U, P, W	Regional, national scales	Advisory board, case study, cooperation, international events
8	EC, ENG, ENV, GE, SO	Consultation, collaboration	Yes	Partners of practice helped to select and concretize topics, gave feedback	D, E, P, W	Regional scale	Case study, cooperation, international events
9	CO, EA, ENV, GE, PS	Consultation, collaboration	Yes	Selection of relevant variables in accordance with partners of practice; partners of practice gave feedback and recommendations and vice versa	B, F, P, U, W	Regional scale	Case study, cooperation, international events, partners
10	AG, AN, EC, ENV, GE, LI	Information, consultation, collaboration	Yes	Partners of practice gave feedback	F, P, W	Regional scale	Case study, international events, partners, tandems
11	ENV, PO, SO, STS	Information, consultation, collaboration	No	Recursive development of frameworks; partners of practice gave feedback	C, D, E, F P, W	National, global scales	Case study, international events, partners
12	AN, EC, ENV, GE, PO, STS, SY	Information, consultation, collaboration	Yes	Partners of practice gave feedback and recommendations and vice versa	B, C, E, F, M, P, W	Regional, national scales	Advisory board, case study, cooperation, international events

†See Table 1 for project descriptions.
‡AG: agriculture; AN: anthropology; CO: communication science; CU: cultural and ethnic studies; EA: earth sciences; EC: economics; ED: education; ENG: engineering (including environmental, industrial, and electrical engineering); ENV: environmental studies and forestry; GE: geography; HI: history; LA: law; LI: life sciences (including biology, population genetics); PHI: philosophy; PHY: physics; PO: political science; PY: psychology; PS: planning sciences; SO: sociology; STS: science and technology studies; SY: systems science.
§B: bilateral cooperation; C: joint case studies; D: joint data gathering and analysis; E: informal exchange; F: interdisciplinary frameworks; M: modeling; P: joint publications; T: interdisciplinary training courses; U: specific development of joint understanding of sustainability or of resilience; W: interdisciplinary workshops.
|Advisory board: set up an international advisory board; Case study: conducted a case study abroad; International events: organization of international events such as conferences or workshops; Cooperation: ad-hoc cooperation with colleagues abroad; Partners: formal inclusion of international partners in project; Tandems: conducting research in a bi-national team.

object could flourish and mutually stimulate each other. In most cases, examples for knowledge integration went along with the recursive character of TSS. For example, Biofuel as Social Fuel's recursive approach aimed at integrating the knowledge and expertise of partners of practice into the modeling process for agricultural landscapes in Germany and Brazil; furthermore, the partners of practice discussed and used the model scenarios.

(8) Contextualization of research: All 12 research groups used case studies as their basic research approach. Ten of the groups did case studies on the regional scale, six on the national scale,

Table 4. Production of different types of knowledge, societal impact, and practice-oriented output of the 12 social-ecological research groups.

Project number[‡]	Types of knowledge produced	Societal impact and practice-oriented output (examples)
1	System, transformation	Appearance in policy papers; consultancy for organizations
2	System, target, transformation	Product Big Jump Challenge; movie
3	System, target, transformation	Coverage in The Economics of Ecosystems and Biodiversity (TEEB), Germany
4	System, target, transformation	Coverage in Food and Agriculture Organisation guidelines on sustainable recreational fisheries; consulted national decision makers; affected angling club stocking policies
5	System, target, transformation	Attendance of policy makers and stakeholders at project events
6	System, target, transformation	Handbook on payments for ecosystem services (PES); coverage in TEEB, Germany; policy paper
7	System, target, some transformation	Organization of dialog rounds; triggered discussions; transdisciplinary brochure
8	System, target, transformation	Guide and "energy compass" for local actors (in German and English); policy paper
9	System, target, transformation	Political decision on adaptation (city of Rostock, Germany); participation in political events on transnational to local scales; triggered political processes
10	System, some transformation	Publication of manual with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ); identification of local, scented rice variety
11	System, some transformation	Policy paper; consultancy; discussion with policy makers at project events
12	System, target, transformation	Organization of participatory policy instrument assessment workshop; policy paper; triggered wider public debate

[†]See Table 1 for project descriptions.

and one on the global scale (Table 3). A focus on Germany and Europe prevailed, but case studies were also conducted in Africa, Asia, India, Latin-America, and USA. Despite pursuing case study approaches, the groups aimed at generating generalizable knowledge, mainly through a comparative case study approach (i.e., comparing cases in a specific country and across different countries). A closer analysis showed that most groups focused on in-depth studies of two to six cases. For example, the Ecosystem Services group explored the linkages between ecosystem services and human well-being in two German case studies. The developed hypotheses were then studied through standardized comparisons across different study sites, including some outside Germany. The group BioDiva illustrated another model by using a tandem device to promote cooperation via bi-national research teams. All groups discussed their results with international scholars, allowing them to reflect on the generalizability of their results. This was done in a variety of ways, for example, conducting international conferences and workshops (all groups), establishing international advisory boards (four groups), formally including international partners in the project (five groups), and having an ad-hoc cooperation with colleagues abroad (eight groups; Table 3).

Outcomes

(9) Production of different types of knowledge: All 12 research groups agreed on the need for new knowledge about the structure and dynamics of complex social-ecological systems. Hence, all aimed at producing system knowledge (Table 4). The groups who also produced target knowledge were mainly those able to agree on a common normative basis. When trying to identify ways to realize these objectives, the limits of social-ecological research became evident. Three of the groups admitted that they only produced some transformation knowledge. This is because their results were focused on system knowledge and contained transformation knowledge only to a certain degree (e.g., Ecosystem Services' selective policy recommendations). However, most of the groups (9 of 12) produced all three types of knowledge. For example, the Besatzfisch project produced knowledge on how the system of stock enhancement via fish stocking works (system knowledge), how to define new goals of fisheries management (target knowledge), and how to transform current management practices via participatory stocking research and active adaptive management (transformation knowledge).

(10) Generating societal and scientific impact: All research groups generated different types of practical output and impact (Table 4). Along with their transdisciplinary approach, this impact was typically made via contributions to policy-making discussions, and sometimes in terms of directing actions and decisions of environmental and business managers and civil society. All groups reported practical impacts such as winning the attention of policy makers on different levels (regional, national, European) via workshops, conferences, and other practically oriented outputs. Four of the groups reported practical impact in some form of direct action such as behavioral change, a political decision resulting from the research project, or a joint campaign with partners of practice. For example, the research group GETIDOS, together with partners from civil society, organized a collaborative campaign for water conservation with a final river parliament in Berlin. A majority of groups (8 of 12) focused on generating policy recommendations via policy papers or the appearance in relevant policy papers and guidelines. In scientific terms, all groups produced outputs in international journals (see Table 1 for examples) and conducted international conferences and workshops (Table 3).

Results of the self-evaluative group discussion: key needs for early career scientists in transdisciplinary sustainability science

Participants need to be open to a plurality of theories and methods and to be explicit about them

As mirrored by the analyzed groups, implicit in all types of TSS is a normative orientation to improve human-nature interactions and to guide desired outcomes. By using and developing theoretical frameworks, TSS helps consolidate the research on a particular sustainability problem. In our survey, the most frequently used theoretical frameworks were the social-ecological systems and social-ecological resilience frameworks. Theoretical frameworks and concepts with broad premises such as these are more likely to provide common ground and offer entry points for natural and social science as well as hybrid scientists. A decisive feature of TSS is openness to a range of theories and methods for the problem focus. In light of fast-changing socio-political environments, this decisiveness is also key during the recursive process in ongoing processes of societal development.

These frameworks and normative assumptions, however, have to be discussed and be made explicit before choosing a course of action in multi-person research projects. Otherwise, this may invite the re-emergence of disciplinary distinctions. Space is needed to render explicit and discuss the various conceptions, their presuppositions, as well as their implications. This is very challenging, especially for a group of early career scientists with few experiences in such a process. It would be fruitful for future research on TSS to reflect further on meta-methods for dealing with normativity across different research contexts and traditions.

Related to this need for openness, the groups analyzed here displayed a wide range of cooperation and a variety of ways to involve research partners and partners of practice. Which approach is best suited depends on the specific research problem and objective. For example, we identified a variety of reasons why no group empowered their partners of practice: engagement with partners of practice that are already powerful (in one case, the decision not to empower practice partners formally was made to prevent them from further strengthening their hegemony in the project region); neutrality as a key issue for working with different stakeholder groups; and the presence of powerful obstacles and barriers that make empowerment difficult to achieve. However, in most cases, it was simply too time-consuming for the early career research groups.

A focus on practitioners and their specific problems at the very beginning of the research process does not necessarily determine the project goals. Goals may emerge during the research process in much greater clarity as novel research outputs are accumulated and trust among the scientists and practitioners increases. Many unexpected issues can arise.

In sum, openness and flexibility are extremely important for TSS at various levels. However, this brings with it inherent project risks, which can include losses of team members and practical partners.

Transdisciplinary translation and knowledge integration need to occur throughout the research process

The experiences of the 12 research groups indicate that it is not sufficient only at the beginning of the research process to conceptualize TSS as driven by real-world problems and to provide translation work among disciplines and the real world. It is necessary throughout the entire research process to navigate across disciplines, so as to provide both transdisciplinary translation and knowledge integration. It has proved indispensable to identify adequate frameworks, terms, concepts, and levels of generalization that can be linked to different scientific disciplines and also relate to real-world issues. Both transdisciplinary translation and knowledge integration require knowledge about specific methods and specific abilities in dealing with nonscientific actors. Both facilitate cohesion within interdisciplinary teams, an additional and challenging requirement for early career TSS researchers.

Researchers need to be open-minded and broadly trained to generate innovation in addressing sustainability problems

Only a few of the group leaders view their research as a continuation of a previous research line, which stresses the novelty generated by TSS. The dialog with nonscientific partners creates more pressure to leave the beaten track of disciplinary research that may be scientifically brilliant but irrelevant from the perspective of nonscientific partners. TSS may resonate more strongly with generalists than with disciplinary specialists, particularly for group leaders. This view is supported by examining the educational background of the lead scientists in the research groups, many of whom come from hybrid disciplines or have an educational background in more than one discipline (e.g., biochemistry and political science; fisheries ecology and empirical social sciences).

DISCUSSION

Our discussion is framed around three main challenges for early career TSS researchers that we condense out of the results of our survey and workshop.

Transdisciplinary sustainability science demands openness to a plurality of research designs, theories, and methods while also requiring shared, explicit, and recursive use of transdisciplinary sustainability science characteristics

Our synthesis of experiences argues for openness to a large variety of research designs, theories, and methods throughout the entire research process to develop solutions for real-world problems (see also Cundill et al. 2005, Wickson et al. 2006). Nonetheless, such openness also requires consideration of TSS's defining properties such as the 10 characteristics defined here. This allows an introduction of the distinct contours of TSS, and in this way prevents an arbitrary “anything goes” attitude (Bergmann et al. 2005, Pohl and Hirsch Hadorn 2006). Our analysis shows that the surveyed groups shared the 10 key characteristics, but how they applied these characteristics differed in many ways. Correspondingly, Ukowitz (2014) calls for a theory of transdisciplinary research, not in terms of content but in terms of the process to generate knowledge and practical solutions. In line with this, Jahn et al. (2012) indicate the emergence of a shared framework of transdisciplinarity, and Lang et al. (2012) present principles for transdisciplinary research that can be applied in different contexts.

Of central importance for such a theory is a reflection on the inclusion of nonacademic partners. Compared to disciplines where established values and norms strongly determine the process of research and the nature of results (Ukowitz 2014), transdisciplinary research is strongly driven by a continuous discussion process among the involved parties from science and practice. The intensity of these discussion processes will vary according to the amount of stakeholder involvement (Maasen 2010).

This takes us to a critical point: the shared characteristics of TSS were in part derived from the SÖF program and were used there as criteria for the funding selection of the 12 research groups. One may thus ask whether researchers applying for a TSS project adapt their research design to meet these criteria via a "reflexive isomorphism" that increases their chances to succeed in raising funds (Nicholls 2010). The danger here is that researchers dogmatically follow the characteristics (Zierhofer and Burger 2007) without reflecting on how they relate to their specific sustainability problem. The discussion and justification of the inclusion of nonscientists in the respective knowledge generation process may be seen as an element of the quality of sustainability science that prevents dogmatic repetition of criteria (Ziegler and Ott 2011). The other characteristics in the framing and implementation dimensions should be reflected upon in a similar manner.

This makes evaluation an important issue in TSS, also for reflecting on the research process and for learning for future research programs. This is a time-intensive process that is demanding for early career research groups, who may need coaching and support by experts in TSS. Future research groups or funding programs may also ex-post evaluate the characteristics of TSS in relation to the outcome dimensions (production of different types of knowledge, generation of societal and scientific impact). By the final funding year of 2014, the 12 research groups in our study had already developed a large bundle of practical and scientific contributions in relation to the sustainability issues raised by each group. However, many practical impacts may only become visible with a time lag (Pregernig 2007). Adequate time periods need to be considered when evaluating TSS outcomes. For instance, research programs may be required that can be initiated by funding agencies of a TSS program with a long time frame of several years so that research impact can be evaluated after a single research project ends.

Decisions about trade-offs must be made because the achievement of both societal and scientific impact is time consuming and difficult to integrate into a scientific career path

Transdisciplinary research is time-costly for at least three reasons. First, the inclusion of nonscientists in the research process is needed, not only to provide necessary data and to open doors for empirical research, but also to act as carriers of knowledge to be included in the generation of new knowledge. This requires a recursive research process with continuous translation and integration work (Lang et al. 2012, Mattor et al. 2014). Second, the required openness of methods and theories demands flexible work across different disciplinary fields. Third, there is a need to produce practical outcomes that are accessible to nonscientists. The time needed to meet these three requirements cannot be invested in writing scientific publications, which is by far the most important criterion in recruiting and tenure evaluation processes (Arlinghaus 2014). The focus on societal impact may conflict with the achievement of scientific impact.

Most early career researchers in TSS are formally evaluated according to traditional disciplinary performance criteria. This leads to a constant struggle between disciplinary and transdisciplinary requirements (Wiesmann et al. 2008). TSS brings about a dual role for the early career scientist, as scientist and as manager of complex social dynamics within the research team and between the team and the outside world, each of which requires specific capabilities and commitments (Ukowitz 2014). This may raise questions of reliability, validity, and credibility for TSS (Lang et al. 2012), a reproach that many members of the analyzed groups had to face in their disciplinary arenas (e.g., faculties and departments). Early career scientists require training and mentoring for managing their time and maintaining credibility in their disciplinary area.

TSS researchers, especially those early in their career, must deal with solving a range of competing objectives and trade-offs (Spangenberg 2011). Certainly, one way to manage these issues is a higher appreciation of outreach and societal impact when scientists' performance is evaluated (Arlinghaus 2014). The current trend, however, is clearly going in a different direction, where papers in high-impact journals and the amount of third-party funding dominate performance evaluations in many countries. Hence, a shift in favor of TSS-specific evaluation criteria requires major institutional changes (for Germany, see Schneidewind 2010).

All of the projects analyzed achieved both practical policy output and impact and scientific output. There were nevertheless trade-offs, and in several cases, a given output and impact could only be achieved with considerable additional work. To avoid excessive demands, early career researchers need to weigh the different expectations and set priorities. They need to plan their approach to TSS carefully while being aware of demands of time and personal commitment. Under these conditions, the "ideal-typical" process of transdisciplinary research as suggested by Lang et al. (2012) frequently becomes unachievable. For example, none of the groups empowered their partners of practice.

Transdisciplinary sustainability science needs both generalist and specialist knowledge and skills

In the analyzed groups, social scientists made up the largest share, many of whom were disciplinary in their education. This confirms Bettencourt and Kaur's (2011) findings that social science contributes the most publications to the field of sustainability science. Luks and Siebenhüner (2007) observe that most of the groups of the first wave of the SÖF program were strongly dominated by social scientists. In the second round, we found there were also many hybrid scientists, representing a broader, more general knowledge base. Indeed, in nearly all groups, at least one researcher represented a hybrid discipline (e.g., environmental sciences, system science, or planning).

The growing number of hybrid disciplines involved may indicate an institutionalization of integrated interdisciplinary approaches in academic education (for "disciplined interdisciplinarity", see Scholz 2011:xix). This could substantially reduce the amount of time required for interdisciplinary translation and integration and help to overcome barriers to interdisciplinarity (Lélé and Norgaard 2005). An alternative perspective is that the increasing involvement of generalists risks losing the productive exchange of disciplinary methods of learning as well as the specialized knowledge needed for addressing specific aspects of research problems (Scholz 2011). Also, according to this perspective, early career researchers from hybrid disciplines are not always well trained in placing their research in established scientific discourses.

We thus think it is important that hybrid scientists demonstrate an education in at least one disciplinary background to bring depth in methods and competencies, in addition to versatility and broad intellectual interest. It is also our experience that leaders of transdisciplinary research groups should be versatile in several disciplines while being experts in at least one discipline, to serve as knowledge brokers among team members (Arlinghaus et al. 2014). Achieving both depth and breadth before running a TSS project imposes particular challenges and risks for early career scientists in regard to length of scientific career development.

CONCLUSION

What is the current practice of TSS research in early career research groups in Germany? What are the shared needs and challenges in the practice of TSS research? We explored these questions through a comparative analysis and self-evaluation of 12 research groups in the second phase of the German funding program SÖF (2008–2014). Based on a literature review and discussions among the research group leaders, we compiled 10 characteristics for TSS and grouped them into three dimensions: framing (focus on real-world problems, normativity, diverse theoretical frameworks), implementation (interdisciplinarity, inclusion of nonscientists, recursive research process, integration of different forms of knowledge, contextualization of research), and outcomes (production of different types of knowledge, generating societal and scientific impact). The comparative analysis of the research groups shows that all 10 characteristics were present to varying degrees in each of the groups. We thus propose that the 10 characteristics developed here may be useful as a guidepost to differentiate TSS from other types of knowledge production. Our list complements previous attempts to classify TSS (e.g., Wickson et al. 2006).

The comparative analysis allowed us to derive three key conclusions. First, there is a substantial diversity in the characteristics and attributes of TSS as implemented by various research groups funded within the same program. Hence, even for early career research groups in the same program, there is no such thing as a monolithic TSS in the sense of a common set of paradigms or epistemic standards. Second, TSS provides opportunities but also substantial risks for scientific career development. Scientists, especially those early in their career, need to deal with competing objectives and are affected by heavy time demands for team building, framing, and interactions with stakeholders. These competing objectives are hard to reconcile. Third, although productively integrating people from disciplinary backgrounds is a frequently acknowledged challenge for interdisciplinary research, we observed a different pattern. Many early career researchers in TSS research groups are already trained in interdisciplinary work. Having completed more than one disciplinary degree or coming from a hybrid discipline, they are better able than disciplinarily trained researchers to build and contribute to interdisciplinary research groups. This development, however, may lead to the downside that some of these generalists are not always well trained in placing their research in established scientific discourses. We advocate that early career research groups should be led by disciplinarily trained researchers who have branched out into interdisciplinary domains during their career development and who have a deep interest in pursuing research in interdisciplinary fields.

Carrying out TSS projects by addressing the characteristics for TSS means overcoming many challenges and engaging in a range of activities outside the comfort zone of traditional science. In TSS projects, high demands are placed on early career research group team members, and research will take more time than is typically granted in standard funding schemes to enable the researchers to complete their scientific qualifications successfully (e.g., Ph. D.).

Future research should compare our results with studies of programs for early career researchers in TSS in other countries. Investigation is needed to determine if our observation of the increasing relevance of hybrid disciplines can also be found in other TSS programs, and what role these disciplines play for the quality of TSS. We suggest exploring the hypothesis that the diversity of the scientific disciplines involved, and the way in which the problem definition is deduced, shapes the research design such that specific types of societal and scientific outcomes are produced. In addition, a long-term evaluation of the future careers of the involved scientists and of the projects' societal and scientific impact would help to understand the trade-offs that early career scientists have to consider.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/7739

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APPENDIX 1

Table A1.1: Operationalization of the derived characteristics of TSS for the questionnaire

Characteristic	Questions operationalizing characteristic
(1) Focus on real-world problems	Which problem was tackled? How was the problem deduced and how was it further differentiated?
(2) Normativity	What is the normative basis/aim of the project? (How did the project contribute to sustainable development and the societal transitions) How was 'sustainable' defined in regards to the project's aim?
(3) Diverse theoretical frameworks	Is the concept of "social relations to nature" considered in the research project and if so, how?[1] Were other concepts of nature-society/social-ecological relations or other theoretical frameworks considered? If so, how?
(4) Interdisciplinarity	Which disciplines are involved? Please list the scientific education/ background of all team members who were involved in the project and their actual disciplinary/ interdisciplinary assignment within the project. How were the different disciplinary research results integrated?
(5) Inclusion of non-scientists	With regard to a transdisciplinary research process, how was collaboration with non-scientists carried out? Which methods were used throughout the respective phases (i. problem framing, ii. knowledge production and iii. integration and application; see last line)? How intense was the collaboration (information, consultation, collaboration and empowerment) and did it change throughout the respective phases (if so, how)?[2]
(6) Recursive research process	Was the research process adjusted according to the conditions of the research field throughout the research process (if so, please state what exactly was adjusted)? Accordingly, were parts of the analysis repeated? Were results sent back to the practitioners and actively developed further?
(7) Integration of different forms of knowledge	Which forms of knowledge integration (methods) were applied (see also 4 and 5)?
(8) Contextualization of research[3]	Was a case study approach chosen? If so, which approach? Which case study in which context was chosen? How was the internationality of your research ensured in regards to a case study approach? Is there any additional contextualization of the research that is not addressed by the other questions of this questionnaire (if so, please elaborate)?
(9) Production of different	Which type of knowledge was generated throughout the

types of knowledge	project (system knowledge, target knowledge and transformation knowledge)?[4] Which type of knowledge was mainly generated in which process phase (see last line)?
(10) Generation of societal and scientific impact	Please name at least 2 examples that demonstrate the generation of societal and scientific impact with regard to the project. [If this is not appropriate at this point of time, name at least 2 examples that are likely to generate an impact on practice or science in the future.] What forms of impact did the project have?
Process phases: i. collaborative problem framing, ii. co-creation of solution-oriented and transferable knowledge, and iii. integration and application of produced knowledge	Is there any additional information or comments about the project phases, especially on aspects not asked for so far – in 5 (inclusion of non-scientists) and 9 (type of knowledge)?

[1] This question was asked first because the theoretical framework of "societal relations to nature" was often named in the SÖF-documents (it was the initial inspiration of the SÖF program).

[2] After the answers were summarized, we asked in addition what are the reasons for not empowering the partners of practice?

[3] The questions in regards to the contextualization of research focus mainly on the case study approach because the questions in regards to real-world problems, inclusion of non-scientists and generation of societal and scientific impact also provide information related to this characteristic.

[4] In the SÖF-documents a focus is set on transformation knowledge; we were nevertheless interested in all three forms of knowledge generated in the projects.