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Effects of transdisciplinary research on scientific knowledge and reflexivity

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Abstract

Transdisciplinary research (TDR) is conceptualized as not only providing societal effects but also benefiting academia. However, recent literature on the evaluation of TDR has focused almost entirely on the societal effects of TDR. A discussion of the scientific effects of TDR is needed to do justice to the potential of this research mode. To date, little empirical research has focused on the effects of TDR on science. Our explorative study addresses this gap. The empirical basis are qualitative interviews with scientists engaged in transdisciplinary research and anchored in three sub-disciplines: environmental sociology, sustainable chemistry, and participatory health research. We identify as main effects of the transdisciplinary research mode: changes in the understanding of scientific problems, changes in the quality of scientific insights, and the promotion of a reflexive turn in science.

Keywords: transdisciplinary research; impact; co-production; joint knowledge production; reflexivity; research evaluation.

1. Introduction and state of research

Recently, many scientific articles have been published on the societal effects of transdisciplinary research (TDR),[1] often dealing with the question how these can be classified or strengthened (e.g. Hansson and Polk 2018; Lux et al. 2019; Schäfer, Bergmann and Theiler 2021; Pärli 2023). In comparison, there has been far less research examining the scientific effects of transdisciplinary research (for exceptions, see Hegger and Dieperink 2015; Belcher et al. 2019; Newig et al. 2019; Jahn et al. 2022). Yet, TDR aims at contributing 'to both societal and scientific progress' (Jahn, Bergmann and Keil 2012: 8). Focusing on the societal effects of TDR alone leads to an overly narrow understanding of TDR that fails to recognize its potential contributions to scientific knowledge as a central quality of this research mode (D'Este et al. 2018). Therefore, we explore the following research question: What effects does the transdisciplinary research mode have on researchers and scientific knowledge? Given our explorative empirical approach, we consider scientific effects very broadly as changes in research practice or scientific results. To highlight this broad understanding, we use the term scientific effects instead of the more common term scientific impact.

Scientific knowledge production in TDR has specific characteristics compared with disciplinary research. The common features of TDR are its orientation towards societal or real-world problems (Pohl and Hirsch Hadorn 2007; Polk 2014), bringing together different scientific and societal perspectives to produce knowledge in an integrative manner (Bergmann et al. 2012; Pohl et al. 2021) and the aim of producing socially robust knowledge (Nowotny, Scott and Gibbons 2001)[2]—although in literature there are slightly different understandings of TDR that emphasize some of these characteristics more than others (Jahn et al. 2022; Lawrence et al. 2022).[3] Other than in disciplinary research, the starting point of TDR is not a research gap within a discipline (Weingart 2010), but the character and complexity of the investigated societal problem. Additionally, practitioners or other stakeholders contribute other forms of knowledge, for example experience-based knowledge or knowledge about the wider context of the TDR project (Enengel et al. 2012; Pohl et al. 2021). Mutual or social learning is an important principle of TDR processes (Vilsmaier et al. 2015; Roux et al. 2017; Knickel et al. 2019), meaning that academic and other actors participating in TDR are open to learning from each other and are able to question their own perspectives and presumptions. In addition to these characteristics of TDR, it is important to consider that most TDR takes place in the form of projects with limited duration and with a consortium of diverse project partners from inside and outside of academia (Wamsler 2017; Newig et al. 2019; Lam et al. 2021).

Traditionally, the effects of scientific findings on science are referred to as scientific impact, which is defined as 'a change in research, which breaks the dominant paradigm and influences future research investigations' (Reale et al. 2018: 299 f.). The established approaches to assess the impact of scientific research are quantitative indicators such as bibliometric and citation metrics, raised funds, number of PhDs, etc. (Hornbostel 1997; Rassenhövel 2010). Measuring scientific impact with these established quantitative indicators has been criticized for a long time. A frequent criticism is that the decision for or against a citation is often not dependent on the quality of an article but on strategic decisions, power structures, and social processes (Fröhlich 1999). Critique of TD researchers mainly addressed the question how to measure effects of research that reach beyond citations (Koier and Horlings 2014; Krainer and Winiwarter 2016).[4] As the established indicators do not adequately cover the characteristics of TDR, criteria for assessing TDR mainly focus on process qualities and societal effects (e.g. Bergmann et al. 2005;

Belcher et al. 2016; Grigorovich et al. 2019). However, the scientific effects faded into the background.

TD researchers repeatedly express concerns that TDR performs poorly in terms of classic indicators such as scientific publications and citations (Ruppert-Winkel et al. 2015; Zscheischler, Rogga and Lange 2018; Bulten et al. 2021). It is argued that fewer scientific publications are produced in TD projects because the time-consuming transdisciplinary research process and the focus on societal effects limit the available time. Thus, literature on TDR refers to the trade-off hypothesis, that is that projects have to decide whether they aim to be scientifically or societally successful (Chambers et al. 2021). Newig et al. (2019) and Jahn et al. (2022) empirically analyse this hypothesis with a large-n sample of TD projects. Their data shows that projects tend to focus on either scientific or societal outputs and impact, while projects with more and stronger practitioner interactions and involvement display more societal impact at the cost of academic outputs and impact in the form of publications and citations (Jahn et al. 2022). However, Lemaître and Le Roux (2021) contradict the assumption of a trade-off between academic excellence and stakeholder engagement. Analysing 25 participatory projects from the field of biodiversity research, they found no correlation between the degree of stakeholder involvement and the level and quality of the academic output.[5]

Regarding the quality of scientific knowledge, however, it is often argued that integration of different disciplinary approaches and practical knowledge in TDR promotes new (Jahn 2008), innovative (Newig et al. 2019), or 'higher quality' (Enengel et al. 2012: 107) scientific knowledge or outcomes. Hegger and Dieperink (2015) show in a survey of 144 researchers involved in a transdisciplinary climate adaptation programme that TDR can draw on a broader empirical data base than disciplinary research. However, according to Zierhofer and Burger (2007), access to empirical data alone is not a specific epistemic quality of TDR. In their view, TDR or problem-oriented research in general adds epistemic value, especially at the level of knowledge integration, but less often at the level of participation.

Another strand of research focuses on the effects on the individual-level of researchers who engage in transdisciplinary processes. The most frequently mentioned effects are learning, capacity building, network building (Grigorovich et al. 2019), and an increase in reflexivity (Nastar 2023). For example, Hegger and Dieperink (2015) note that the researchers involved in the interview study strengthened their reflexivity and were able to build new networks. Pregernig (2007) shows in a case study that the involved researchers learned to collaborate and communicate more productively with other disciplines through TD collaboration. A more thorough understanding of the real-world problem is another individual learning effect observed empirically (Grigorovich et al. 2019).

Considering these different dimensions of scientific effects, we would like to contribute to the debate around the effects of TDR by analysing the effects of the transdisciplinary research mode on researchers and scientific knowledge with an exploratory empirical approach. In the next sections, we present our research design and sample. The results section includes three parts: the understanding of scientific problems, the quality of scientific insights, and the reflexivity of researchers. The discussion situates the results in the existing literature and addresses the limitations of the presented study.

2. Research design

For our empirical study, we chose a qualitative approach to address the research question in an exploratory way. We deliberately chose three very different sub-disciplines as fields of study. In this way, we obtained a wide variety of contexts and data on the application of transdisciplinary research. The focus of our study is on the commonalities regarding the scientific effects of TDR that emerged in the diversity of these contexts.[6] The selected sub-disciplines are

- Environmental sociology is a sub-discipline of sociology dealing with the relationship of societies to their (natural) environment and, increasingly with questions surrounding the guiding principle of sustainable development (Groß 2011; Wendt et al. 2018).
- Sustainable chemistry is a guiding principle rooted in sustainable development rather than a sub-discipline of chemistry. It promotes an approach that considers the entire life cycle of chemical products, including health, environmental, social and economic aspects, as well as planetary boundaries (Kümmerer 2017; Blum et al. 2019).
- Participatory health research is an approach in the field of public health. Participation is the defining feature of this approach: people affected by or relevant to the research object are involved as co-productive actors in the organization and implementation of the research process (Wright, Allweiss and Schwersensky 2021).

In this paper, we refer to these three contexts as 'sub-disciplines' for the sake of simplicity. In Supplementary Data 1, we provide anonymized examples of transdisciplinary projects with contributions from these sub-disciplines. We limited our study to Germany in order to keep potentially relevant contextual factors such as national research and funding policies or country-specific structural and cultural features of the science system as homogeneous as possible.

We interviewed 22 researchers who are well established in their sub-disciplines and who also have experience of conducting transdisciplinary research (see Table 1). The interviewees from environmental sociology and sustainable chemistry tended to have a disciplinary background and moved towards transdisciplinary research in the course of their careers (T-shaped training, see Guimarães et al. 2019). Most of them had a lot of experience with interdisciplinary research due to their focus on environment respectively sustainability. The interviewees from participatory health research tended to have a social science background but were active in the highly interdisciplinary field of public health. In general, all interviewees tended to have positive attitudes towards transdisciplinary research.

As a criterion for disciplinary establishment, the person should hold a professorship or have completed a habilitation.[7] As the reality of TDR projects often differs from the ideal-type description of TDR in the literature (see above), we identified four key characteristics of TDR. Potential interviewees had to have experience with at least one research project that fulfilled all four characteristics to at least some degree:

- addresses (complex) societal problems
- allows for the participation of non-scientific actors (to varying degrees) in the research process

Table 1. Overview of empirical data

	Environmental sociology (S)	Sustainable chemistry (C)	Participatory health research (H)	Total
Number of interviews	8	7	7	22
Gender distribution (male/female)	m: 2, f: 6	m: 7	m: 5, f: 2	m: 16, f: 8
Ø interview duration	00:59:10	01:09:36	01:15:24	1:07:39
Additional data: Dialogue Forum (DF)	Online-Workshop with nine of the interviewees, 25 June 2021. Duration: 4 h.			

- integrates knowledge from different disciplines and non-scientific actors
- aims at generating both scientific and societal effects

We identified potential interviewees through online resources and a snowball approach, asking interviewees at the end of each interview if they knew of colleagues in their field that we could contact.

We conducted qualitative semi-structured interviews (Patton 2002). The interview guide contained open questions on the experiences and understanding of TDR, observed scientific effects of TDR, difficulties for TDR in their own disciplinary environment, and possibilities for promoting TDR (see Supplementary Data 2). The interviews referred to the interviewees' general experiences with TDR, not to specific projects. We conducted all interviews by telephone or video conference (depending on the preference of the interviewee), recorded, and transcribed them. All interviews were conducted in German; we translated relevant quotations into English for this paper. The data material was analysed based on qualitative content analysis (Mayring 2000): We coded deductively according to previously developed categories but also created new categories inductively from the data, using the programme MaxQDA to structure the data.[8] At a workshop called 'Dialogue Forum', we presented the most promising categories to some interviewees as interim results. We transcribed the discussion and used relevant comments to focus our findings.

3. Results

We found three overarching effects in the empirical data: Compared to disciplinary research, TDR changes the understanding of scientific problems and the quality of scientific insights. Furthermore, TDR promotes the reflexivity of the scientists involved. We elaborate on these effects in the next three subchapters. The following subchapter deals with open issues and challenges related to scientific effects of TDR. At the end of the section, a table provides an overview of the empirical results with examples from the research practice of the interviewees.

3.1 TDR changes the understanding of scientific problems

In disciplinary research, research gaps are usually determined according to disciplinary criteria. The problems and questions addressed should be relevant primarily from a disciplinary perspective rather than a societal perspective. The statement of an interviewee illustrates this for the field of chemistry:

> *Sometimes in science, we just want to make a new material because we think it's cool for some reason, or want to prove that it's possible to make such molecules. The application is often secondary. (18C_11)*

In contrast, transdisciplinary research deals with societally relevant complex problems (10S_21; 14S_49). The interviewees see transdisciplinary research as the appropriate approach to deal with such problems, which are often found in the field of sustainability research. A chemist describes this effect using the example of plastic: *'the plastic problem is a problem that we cannot solve in a disciplinary way, you need different disciplines, as broad as possible, and you maybe even need even politics'* (18C_104). In our interviews, we identified three different ways in which the understanding of the scientific problem changes when a transdisciplinary research mode is used instead of a disciplinary research approach to deal with complex problems: Extending, revising, and sharpening the scientific problem definition.

3.1.1 *Extension of the research subject*

One way the scientific problem may change when using the transdisciplinary research mode is the extension of the research subject. One interviewee describes this process using the example of a transdisciplinary research project on climate protection in urban areas:

> *We had to select the fields of action and the practice partners absolutely wanted waste management to be included. I would never have come up with this topic on my own. [. . .] In retrospect, it turned out to be a very exciting field of action, where I can extract something interesting for research. (13S_45-47)*

Through interactions with practice partners, the scientific actors realize that there are important issues of the problem they would not have noticed from their disciplinary perspective. Broadening the scope of the problem changes the scientific view of the problem, which is assumed to also advance the scientific knowledge production. However, not only the exchange with practice partners but also the interdisciplinary collaboration can lead to a broadening of the problem scope. For example, a chemist describes how interdisciplinary research is structured in food chemistry with different disciplines along the value chain. He use the same structure to identify new research questions (19C_10).

Another aspect is raised by a sociologist, who says that natural scientists are increasingly turning to them because natural scientists alone are *'no longer getting anywhere in their field'* (11S_27). It is of no use to the natural sciences *'if we now know how the loss of biodiversity works or how climate change somehow manifests itself here and there'* (ibid.). As the problem perception of the natural scientists changes, they are more willing to cooperate with social sciences in order to develop relevant knowledge and to do justice to the complexity of the research subject.

3.1.2 *Revision of the scientific problem definition*

In some cases, it is not sufficient to merely expand the subject under research. In particular, interaction with practice

partners in the transdisciplinary research process might reveal that the problem definition assumed by the scientific actors during the project conception is biased or wrong. The interviewees mentioned some project examples where the definition of the relevant problem was revised or *'quite clearly'* (22S_24) changed by collaborating with practitioners. For example, one interviewee describes an experience from a project about day-care centres:

> *We had the situation when the parents [involved in the project] said in the first funding phase, 'we don't want to do research on the transition to day-care', which we had planned in the application [. . .]. If the parents say that their problems are more related to the children's stay at the day-care than to the transition to day-care, then we have to change the project in that direction. (8H_91)*

The interviewee says that only after the project has started they could tell what the parents perceived as a decisive issue (8H_47). In this case, the main problem was communication with the kindergarten teachers. As the parents objected to the original project proposal, the problem definition was revised and adapted accordingly.

3.1.3 *Sharpening the scientific problem definition*

In many transdisciplinary projects, scientific actors provide a first rough problem definition. Ideally, this problem definition is sharpened in a methodological approach at the beginning of a research process together with practitioners to confirm and strengthen its relevance. An example from the field of water management illustrates this procedure:

> *We first check whether the citizens actually think that water has become scarcer and who is to blame for this and what can be done about it, and so on. In other words, we first have to test whether what we consider problematic is actually seen as problematic in society. (11S_11)*

The aim is to determine the problem perception of societal actors at an early stage and then jointly define a problem that can be scientifically addressed. The interviewee contrasts such an approach with social inequality research or environmental sociology, where the problem is defined only from a scientific perspective. An early relevance check allows scientific actors to *'ground'* (20S_21) and sharpen the problem definition. If the relevance of the problem is not given from the perspective of practice actors, the feedback comes quickly, as one interviewee retells what they heard from practice partners: *'What you are discussing here is a scientific topic; it may be interesting for you. For us, it has zero relevance to everyday life'* (20S_21).

3.2 TDR changes the quality of scientific insights

Transdisciplinary research enhances the quality of scientific insights due to the broad expertise from science and practice: Transdisciplinary results are characterized by methodological innovations, improved data quality and insights, and timeliness, as our empirical evidence shows.[9]

3.2.1 *Methodological innovations*

The interview partners from environmental sociology and participatory health research report various methodological innovations in transdisciplinary projects.

One form of innovation is developing new or adapted methods. Two interviewees reported how they adapted existing methods for a specific case, and methods from one discipline were used in another discipline due to interdisciplinary cooperation (8G_65; 22S_30). For example, in one project, engineers used a participatory method for measuring waste quantities and analysing material, which they had only learned about in the project (22S_30). One interviewee from participatory health research emphasizes that transdisciplinary research is not even possible without method development or adaptation, *'because in the collision of different discourses or backgrounds, you also have to find new ways'* (17G_41).

Two of the interviewed sociologists say that the experience of TDR has changed their approach to social science methods. One sociologist observed that the work experience in a transdisciplinary real-world laboratory caused a shift from quantitative to qualitative methods. Because of their personal enjoyment of *'conversations with different actors'*, they now tend to *'incorporate group discussions into research situations'* (13S_81). The other sociologist says that TDR has made them more aware of the social biases in the sampling process. They are now using more participatory formats in a disciplinary project to counteract this (6S_21).

Another form of methodological innovation are improved data validation processes. If actors from the field are involved in the development of survey instruments, it ensures that those factors are considered that are relevant for the respective contexts. An interview partner from participatory health research explains this using the example of a social science questionnaire survey:

> *When I do a survey in a city [. . .] I also have to know the specifics in that region. What happened there in the last few years? What kind of discussions were there? [. . .] There can be a cooperation, for example, with the local district office or the mayor [. . .]. I can include such things in the questionnaire, even if it is only as a control variable [. . .]. This means that only through this cooperation am I able to design the survey instrument more closely to this region, to the sample or to the target group. (9H_19)*

Practice actors are also valuable partners in the evaluation of research results: In the same research project, the practice partners supported the scientists in interpreting the survey results. With their contextual knowledge, the practice partners can help to better classify and understand the answers in a survey—for example, from a specific region—in a way that the scientists could not do on their own (9H_19).

While the interviewees working with social science methods reported various methodological innovations, the interviewees from chemistry stated that their disciplinary methods remain relatively unaffected by TDR. *'The internal original research logic develops according to other logics and is little influenced by the transdisciplinary research concept'* (2C_71). If methodological changes take place, these are additions to disciplinary methods of chemistry, not adaptations (3C_7).

3.2.2 *Improvement of data quality and knowledge generation*

All interview partners confirmed that their data and the generated knowledge significantly improved through close cooperation with practice partners. A researcher from participatory health research reports that they were only able to determine *'how the field actually ticks'* (DF_574) by working together

with practitioners. Another interviewee from participatory health research emphasizes that insights in this field must be *'generated from experience [. . .] from practice'* (8H_61) and *'not in the laboratory as an experiment'* (ibid.). Interview partners from chemistry confirm that knowledge about production methods in industry and information about consumer needs improve results (18C_67; 19C_42). In a similar way, a sociologist says they have learned from their years of experience with transdisciplinary projects *'to think very intensively about practice [. . .], into the perspectives and problems of other actors'* (10S_9). Another sociologist *'learned a lot about how this specific administration works'* (6S_19) by attending their meetings over a long period. For the interview partners, these insights into their respective fields of research have the effect of improving the knowledge base for their scientific findings.

Several interviewees also told us that working with practitioners gave them access to empirical data that they would not have had access to in a disciplinary constellation. A sociologist says about their research on companies that it *'would not have been possible without this transdisciplinary cooperation'* (22S_34) to interview employees from different hierarchical levels. Access to these interview data contributed to a more complete picture of the subject under investigation. A chemist describes how they are only able to answer certain technical questions by working closely with practitioners, such as—in this case—farmers or agronomists who contribute their own expertise on a crop (19C_36). Cooperation with practitioners thus opens up completely new methodological possibilities and a much broader database.

Several interviewees from participatory health research say that only participation of those affected makes it possible to produce new knowledge about these groups (9H_3; 16H_29; 21H_7). Joint research with those affected is at the core of this approach. An interview partner talks about a project that conducts participatory research with people with learning difficulties:

> *this has generated new insights into how people with learning difficulties view health, but also what they are capable of in terms of shaping their lives, and how messages about health should be developed and disseminated among other people with learning difficulties. (4H_25)*

Those affected have their own specific knowledge regarding their own situation. This knowledge enriches the research findings and thus creates added value for the results.

TDR also promotes the development of new knowledge in the area of concepts and theories. One respondent from health research describes how they used to cooperate with practice partners *'naively'* (16H_41) and not based on social theory. By working in a transdisciplinary setting, they came to grips with social science concepts such as *'structure and agency'* (16H_47). Today, they say, they use these concepts to structure their research processes and develop results that are more applicable. This process has *'definitely generated a change for my actions as a scientist'* (16H_41).

3.2.3 *Timeliness of results*

Another finding from the interviews is that results from transdisciplinary research are often more up to date than disciplinary research results. One reason for this is the real-world problem-orientation of the research. The interviewees explained that the proximity of transdisciplinary research to relevant societal problems also means that their findings are highly topical. TDR is, as one sociologist puts it, *'oriented entirely towards highly topical issues, preferably towards topics that will only become topical in three years' time'* (14S_21). As an example, they cite the topic of digitization and sustainability. *'There has been transdisciplinary research on this for ten years, while sociological research has only just started to deal with it'* (ibid.).

Collaborations with practitioners might lead to innovative scientific results. As one interviewee from participatory health research describes:

> *We are able to generate more unexpected new findings for which we don't already have a theoretical basis in some way. So the strength is to actually discover the new. (9H_59)*

A chemist states that the exchange with actors from practice leads to *'being a bit in touch with the pulse of time'* (19C_40). They report that through contact with industrial actors they sometimes learn that processes are implemented differently in practice than assumed. They then carry this information back into their professional context (19C_40).

Transdisciplinary research also enhances the topicality of research because it typically investigates processes of social change. Researchers can accompany such processes in real time. This enables a topicality and detail of findings—*'very rich in terms of understanding such a process'* (6S_19)—that would not be possible the same way in retrospective reconstructions.

3.3 TDR promotes a reflexive turn in science

In our empirical material, a third effect of transdisciplinary research was evident: the increase in reflexivity. This change affects individual researchers. Potentially, however, an increased level of reflexivity could also trigger broader changes in science. In this context, one participant in our Dialogue Forum spoke of a *'reflexive turn'* (DF_202) that could be triggered in disciplinary science if the *'epistemological foundation'* (ibid.) of transdisciplinary research were to be strengthened even further. We found different dimensions of reflexivity in the data.

3.3.1 *Increased reflexivity at the level of the individual researcher*

Transdisciplinary research presupposes reflexivity as an individual quality. However, reflexivity is also promoted (and challenged) through constant confrontations with other perspectives during the research process. One interviewee describes transdisciplinary cooperation as *'constant irritation'* (14S_49). They point out that transdisciplinary researchers are used to moving between different professional and social contexts and adopting different perspectives:

> *you have to go out again and again, observe, be inside, reflect on yourself [. . .] stay inside, change and so on. This constant going out, going in, zooming in, zooming out is what you get most in transdisciplinary research. (14S_49)*

These irritations in TDR and the attitude that *'nothing is taken for granted'* (14S_49) are important *'for the development of research personalities'* (14S_49). The interviewees

consider these learning processes as *'extremely enriching'* (10S_45) and as a possibility to *'see the world with different eyes'* (ibid.). Reflexivity in the sense of constant mental flexibility, openness and questioning one's own position is seen as relevant both on a personal level and for academic work:

> *that you have to remain mobile, that you can't rest on certain, resources, bodies of knowledge or points of view, and that you also question how you think, what you think, how you work something out. I think that's good for science. And that's good for you as a person. (17H_75)*

However, it is challenging to deal with other perspectives and to question one's own perspectives. For example, one sociologist describes it as *'enormously difficult'* (11S_45)—but at the same time necessary for their research—to engage with perspectives from the global South about *'the knowledge or the way of dealing with and thinking about nature'* (ibid.) that are not familiar to them. Another interviewee emphasizes that researchers in transdisciplinary processes should have the attitude that *'even as a professor, I can still learn quite a lot from someone'* (1H_47).

3.3.2 *Increased reflexivity regarding the limitations of disciplinary perspectives and methods*

Experiences in transdisciplinary research trigger reflections on the discipline in which the academic career began. This was the experience of all our interview partners. A chemist reports that their experiences with transdisciplinary research revealed the *'blind spots'* (2C_81) of their discipline.

Some sociologists report that their experiences with TDR have triggered a reflection on the theoretical concepts they use. The interviewed sociologists noticed a lack of theoretical connection to real-world processes. One interviewee recounts how the practical insights showed them that the considerations they had *'theoretically made up for myself as a sociologist [. . .] did not correspond to reality'* (10S_9; also 13S_71; 22S_10). For another sociologist, the limitations of their theoretical sociological concepts became clear through contact with the practice of politics and administration. These insights were an *'extreme gain in knowledge [. . .] what really differs and what that then means'* (13S_71). An interviewee from participatory health research describes how they became aware of the limitations of the concepts of their own discipline by working in a transdisciplinary setting and by using concepts of other disciplines that were helpful (16H_47).

The interviewees also reflect on how research questions are defined in disciplinary research. For example, one sociologist says that research on social inequality or environmental sociology is also problem-oriented, but in contrast to TDR, questions are dealt with *'that we [the social scientists; emphasized] think are relevant for society'* (11S_11). Another sociologist says that they would have conducted their transdisciplinary project *'quite differently if it had been a basic research project [. . .] and other insights would have come out of it'* (13S_47). The experiences made in transdisciplinary research showed how contingent a purely disciplinary perspective can be and how it affects the research approach and the insights gained.

Dealing with transdisciplinary research processes sensitizes researchers to the limits of their disciplinary research methods (22S_24). One sociologist notes that they can develop richer insights with TDR than with the usual sociological interview methods, which collect data only at one point in time and retrospectively. They compare TDR with participant observation in ethnography (6S_19), which results in much richer data material:

> *If I compare this [a qualitative interview] with such a process and an insight into the work processes of the city administration [in the transdisciplinary research project], this is of course ultra superficial compared to the insight we got there in the last few years. (6S_17)*

3.3.3 *Increased reflexivity about questions of responsibility and power of science*

Transdisciplinary research makes researchers more aware of the power, but also the social responsibility of science. The interview partners from sustainable chemistry strongly emphasized the responsibility that science has towards nature and humanity. The broader view of societal problems practiced in TDR made the interviewed chemists aware of how narrow a disciplinary perspective on these problems is, leading to unintended side effects of scientific actions that are overlooked (3C_75-77; 15C_45-47).

> *Actually, it's end-of-pipe, it's all afterthought, and we've got ourselves into a situation with so much material and energy throughput. Then, you try to make that material and energy throughput somehow environmentally friendly. But the fact that you actually have to change and reduce it is not an issue. So the basic question, where do the problems actually come from, is not asked. (2C_47)*

The chemists criticized that their discipline takes too little responsibility for the problems of sustainability and their roots and thus itself contributes to its perpetuation (2C_21-23; 15C_33; 18C_49). Because of their focus on pure basic research, chemistry would not ask *'Why is [. . .] an environmental chemistry finding actually a problem and what does that mean for society?'* (2C_7). One reason for the narrow disciplinary perspective and the focus on developing new substances is the close relationship with the powerful chemical industry (2C_33). However, a sociologist also mentions ignoring co-responsibility for social problems as a problem of their discipline, producing *'ivory tower results'* (6S_61).

Another aspect of increased reflexivity mentioned by respondents from participatory health and social sciences touches the interpretative power of science for social phenomena. The experience that in TDR definitions of terms, research questions, or research results are not determined solely from the perspective of a single discipline stimulates many researchers to reflect on the power inherent in research. One interview partner from participatory health research describes it as the *'most positive effect'* (8H_129) of TDR that it encourages a reflection on what interpretative power scientific definitions can have:

> *that you also create social facts with research. [. . .] by producing social facts you also contribute to poverty, for example, by proving that some people are disadvantaged, and stigmatisation effects can result from this. (8H_129)*

One interviewee from participatory health research said that cooperation with scientists from other disciplines and with actors from practice stimulated a reflection on their own *'normative settings'* (16H_203). A chemist emphasizes that

chemistry assumes a neutral position of the natural sciences, which would be *'never true'* (2C_7). Reflecting their disciplinary perspectives and limitations therefore encourages researchers to question normative assumptions and claims of scientific objectivity.

3.4 The other side of the coin: open issues and challenges regarding TDR and its scientific effects

In the sections above, we have shown what added value transdisciplinary research has for science. However, the interviewed researchers also raised open questions and mentioned challenges regarding transdisciplinary research representing the 'other side of the coin'. These aspects complement the findings on the scientific effects of transdisciplinary research and thus provide a more comprehensive and realistic picture for further informed discussions on this topic.

3.4.1 *Barriers to processing and disseminating insights from TDR to the scientific community*

We have shown that integrating different bodies of knowledge in TDR can lead to a better understanding of scientific problems and a higher quality of scientific insights. A sociologist sees *'a huge potential'* (6S_61) for gaining scientific insights on processes of social change that are often investigated in TDR. However, interview partners from sociology and participatory health research drew attention to a problem: In many transdisciplinary projects, it is not possible to analyse all insights according to disciplinary standards. Often time for writing scientific papers in transdisciplinary research projects is missing because of the time-intensive collaboration with practice (10S_47). Capturing scientific insights from TDR in a way *'that you reflect on your own role in it and systematise it in such a way that you can publish the results'* (6S_61) is a challenging task. The interviewees criticize the lack of *'follow-up financing possibilities, after three years it's over, no matter how complex the problem is'* (10S_11). As a possible solution, they suggest that a second funding phase could be set up for the scientific analysis of data, similar to funding phases for transfer (6S_41; 10S_11). Further, interviewees from participatory health research in particular point out that transdisciplinary methods make disciplinary publications and thus scientific recognition more difficult, because the methods are unusual by disciplinary standards or have to be pragmatically adapted to the demands of practitioners (9H_15). For example, an interview partner from participatory health research reports great difficulties in publishing their transdisciplinary insights in a journal for qualitative social research because their workshops with practitioners did not meet the disciplinary demands of the editors (8H_45). For time and methodological reasons, the scientific insights from TDR therefore are not used further and do not find recognition in the scientific system.

Another reason why transdisciplinary projects produce fewer publications than comparable disciplinary projects is the fact that transdisciplinary research often takes the form of regional case studies. These are *'very time-consuming'* (12S_108), as a sociologist says, but at the same time, they are little recognized within their discipline. An English-language journal, for example, *'is not that interested [...] in what we found out in the Schwäbisch Gmünd district'* (9H_31). Comparative case studies that would favour generalization are difficult to implement due to the strong context dependency of TDR (12S_96) and the fact that *'there are no randomised controlled trials in municipalities'* (8H_61). The strong context dependency of TDR thus does not correspond to mainstream research.

3.4.2 *Different expectations regarding TDR's claim to contribute to solving societal problems*

Transdisciplinary research claims to contribute to the solution of complex societal problems. In the interviews, however, the question was raised how complex (or 'big') the societal problems may be to be successfully addressed in TDR projects. For example, an interviewee from sociology (10S_2) wonders whether a research project with typical resource constraints (e.g. three years duration) could really handle the level of complexity that the problem would demand:

> *You can say, 'how do we want to expand retention areas for recurring floods, how do we deal with the constellation of interests?' Okay, but that is not the complexity I'm talking about, that which we are dealing with [...]. [To] even begin [to] understand and deal with [...] the truly complex problems, you need quite different institutional arrangements. (10S_2)*

Not all interviewees consider complex problems important for TDR. For example, one interview partner from sociology argues that dealing with complex societal problems is *'not necessarily constitutive'* (13S_5) for transdisciplinary research. For them, the central feature is that additional sources of knowledge and knowledge producers are included in the research process. However, this can *'in principle also be done with very small questions'* (13S_5).

3.4.3 *The need for reflexivity regarding the independence of science in TDR*

The interviewees also point out that TDR experiences must be critically reflected with regard to the independence of science. The interviewees reported examples of practice partners that used cooperation with researchers to strengthen their own interests in their work context. For example, a sociologist reports that they were researching the sustainable transformation of an urban space, which was *'controversially discussed'* (6S_63) in the city. In this politically conflict-laden context, the sociologist feels partly *'instrumentalised'* (ibid.) by the municipality, which is a partner in the project. They say that the researchers in the project sometimes take on a *'legitimising role'* (ibid.) in order to strengthen the interests of the city and the municipal administration. One interviewee from participatory health research had a similar experience: In a project, they were asked by one municipal practitioner to influence other practitioners regarding the direction of the research (8H_91).

Not quite as extreme but touching on a similar problem, some of the interviewees have the impression that in TDR scientific interests sometimes come second to societal interests. According to a sociologist, the *'pressure to somehow find compromises'* (13S_177) is very pronounced in TDR, in contrast to purely disciplinary research. Another sociologist says that if they were to conduct research on transformation processes alone, they would be

> *much freer to ask questions than when I have to do it in collaboration with the partners who are themselves in the*

Table 2. Summary of results

TDR changes the understanding of scientific problems: The integration of different bodies of knowledge of practice actors and different scientific disciplines in transdisciplinary research processes has the effect that the research subject can be extended and the definition of the problem can be corrected and sharpened.	
Dimension of scientific effect	*Example*
Extension of the research subject	Transdisciplinary cooperation with practitioners showed that waste management is a relevant field of action in municipal climate mitigation. With a disciplinary approach, the researchers would not have recognized this aspect.
Revision of the scientific problem definition	Feedback from parents showed that the real problem is not the transition to day-care, as assumed by the researchers, but the children's stay at the day-care and the communication with kindergarten teachers. The problem definition was adjusted accordingly.
Sharpening the scientific problem definition	At the beginning of a research project about water management, it is tested with citizens what they actually perceive as problematic. The research problem is defined accordingly.
TDR changes the quality of scientific insights: Working on the research subject over a longer period of time and in close proximity to practice leads to methodological innovations, broad data, and up-to-date findings.	
Dimension of scientific effect	*Example*
Methodological innovations	Participatory processes improve the preparation of a questionnaire and the validation of results.
Improvement of data quality and knowledge generation	Working closely with people with learning difficulties in a research project provides insights into their perspectives on various issues that would have remained invisible in a non-participatory approach.
Timeliness of results	Research in close collaboration with industrial actors shows the chemist how the processes are implemented in practice. This information can be used in further research.
TDF promotes a reflexive turn in science: Confrontation with other disciplines and perspectives of practice partners promotes the reflexivity of researchers on a personal level, regarding their disciplines, and regarding the responsibility and power of science.	
Dimension of scientific effect	*Example*
Increased reflexivity at the level of the individual researcher	Researchers learn to remain flexible in their own way of thinking and to constantly question it. This helps to develop as a person and as a researcher.
Increased reflexivity regarding the limitations of disciplinary perspectives and methods	Insights into practice show sociologists how far the theories of their own discipline often are from reality.
Increased reflexivity about questions of responsibility and power of science	The broad approach to sustainability problems in TDR shows the chemist how narrow the perspective of their discipline usually is, and that the disciplinary approach often neglects the societal causes and consequences of these problems.
Open issues and challenges related to TDR and its scientific effects concern barriers to scientific processing of insights from TDR, the status of 'complex problems', and reflexivity regarding the independence of science in TDR.	
Open issues and challenges	*Characteristics of issues and challenges*
Barriers to processing and disseminating insights from TDR to the scientific community	Lack of resources as well as methodological challenges hinder the scientific use (e.g. publication) of the rich findings from TDR processes and thus the recognition of TDR within academia.
Different expectations regarding TDR's claim to contribute to solving societal problems	Some researchers relate the complexity that TDR can deal with to practitioner involvement and knowledge integration rather than to the problem to be solved, which can also be 'small'.
The need for reflexivity regarding the independence of science in TDR	Collaboration with practitioners carries the risk of political instrumentalization of the research process and that scientific interests might be neglected, which should be reflected.

> *political game and have to justify to others what questions they are helping to ask. (13S_177)*

Another interviewee points out that many projects focus on societal effects to motivate practitioners to participate in the project. However, there is a danger that scientific interest are neglected and '*everything is focussed on the practical needs*' (10S_11). These statements show the need to reflect on the role and independence of science in transdisciplinary collaborations, especially in cooperation with political actors, and on the interests and concerns of scientific actors.

3.5 Summary of results

Table 2 summarizes our empirical findings and provides examples for each dimension of effects that were mentioned in the interviews. They will be discussed in the next chapter.

4. Discussion

Our results illustrate the *scientific added value* of transdisciplinary research for knowledge generation. First, transdisciplinary research contributes to scientific knowledge by

changing the understanding of scientific problems. The empirical results show that the integration of knowledge from practitioners and other disciplines leads to an early sharpening or adaptation of the problem definition. These results complement the work of Pearce and Ejderyan (2020), who point to the relevance of joint problem framing in TDR to address real-world problems. Second, our results indicate how TDR changes the quality of scientific insights. The empirical results show that transdisciplinary collaboration leads to more and better data about the object of research, methodological innovations, and to up-to-date research results. According to Jahn, Bergmann and Keil (2012: 3), integration 'establishes a novel, hitherto non-existent connection between distinct entities of a given context', which is confirmed in our data.

In TDR, a distinction is often made between system knowledge, target knowledge and transformation knowledge (Network for Transdisciplinary Research (td-net) and Pohl 2022). System knowledge, as the knowledge of 'what is', has the greatest proximity to scientific knowledge in the classical or disciplinary understanding. Our results on changes in the understanding of scientific problems and the quality of scientific insights can be related to (newly generated) system knowledge. However, the results are also relevant for orientation knowledge ('what should be') and transformation knowledge ('how is desired change possible'). The increased scientific reflexivity we observed in the data can direct towards target and transformation knowledge: On the one hand, increased reflexivity is linked to individual learning and thus transformation processes. On the other hand, the current academic system and disciplines are critically reflected, which may provoke thoughts of desirable changes. The findings suggest that the contribution that TDR makes and could make to both system knowledge (through a broader problem framing and through a change in the quality of insights) and to orientation and transformation knowledge (through reflexivity of researchers and changes of the science system) is still underrecognized and under-appreciated by the scientific community.

However, we have also shown that there are barriers to processing and disseminating the scientific insights generated by TDR. The challenge of how to formulate general findings from context-dependent case studies is well known (Krohn 2008; Adler et al. 2018; Nagy et al. 2020). Processes of co-production and knowledge exchange between academia and practice use resources and may imply different forms of costs (Karcher et al. 2022). As results from transdisciplinary collaboration need to be presented and disseminated according to existing scientific standards, cost-intensive co-production processes may reduce the scientific output of projects. Jahn et al. (2022) confirm that projects with more intense collaboration between research and practitioners produce fewer scientific output. As only published results of transdisciplinary research are available to other researchers for critical contestation or citation, lower publication rates mean that the insights generated in transdisciplinary projects cannot be circulated to the extent that could be possible, and scientifically relevant findings from TDR remain unrecognized (Jahn 2023).

Based on these empirical results, we would like to emphasize that time and financial resources as well as careful project planning are important factors for disseminating scientific findings from TDR. For example, adequate resources are needed to systematically document, reflect on, and evaluate the scientific results of a transdisciplinary process, and to feed them back into a (disciplinary) scientific community. One possibility could be to fund scientific writing phases after the end of a project in order to prepare the results for scientific publication and thus promote the scientific effects of transdisciplinary projects.

Our empirical results further show that TDR promotes a reflexive turn in science. The main reason for this is that researchers in TDR processes are confronted with other disciplines and practitioners' perspectives. This observation was also made by others (e.g. Jahn, Bergmann and Keil 2012; Nastar 2023). However, our data show that scientific reflexivity has different dimensions that are rarely distinguished in the literature (for exceptions, see Popa, Guillermin and Dedeurwaerdere 2015; Knaggård, Ness and Harnesk 2018). For example, Nastar characterizes the prevailing understanding of reflexivity in TDR as 'being critical about one's position, epistemic and normative orientation in research, and the effects of these elements on the research processes and outcomes' (2023: 3). We argue that it is productive to distinguish an increased reflexivity at the level of the *individual researcher* engaged in transdisciplinary research from an increased reflexivity towards one's *own discipline* and towards the *academic system*.

Researchers engaged in transdisciplinary processes acquire personal skills such as openness and appreciation including other perspectives and the ability to endure constant irritation and to question oneself.[10] An increased reflexivity on the personal level can be seen as a basic personal competence that researchers will use in their future research, both in transdisciplinary and disciplinary research, and generally in their personal acting and thinking.

On a professional level, researchers engaged in transdisciplinary processes become aware of the limits of disciplinary methods and perspectives and of the responsibilities of science. As our results show, the experience of transdisciplinary research leads disciplinarily trained researchers to see disciplinary science no longer as the only seemingly 'natural' way of doing science, but as only one possible way that can and should be critically reflected upon.

A growing body of literature focuses on the roles of researchers in transdisciplinary processes (e.g. Wittmayer and Schäpke 2014; Horlings et al. 2020; Hilger, Rose and Keil 2021). Bulten et al. (2021) explore the tensions that arise from different role expectations and performances, both from actors involved in the transdisciplinary research process, but also from societal expectations about what scientific knowledge is and how it should be developed. Our results show that tensions or irritation increase the reflexivity of researchers towards their roles and scientific practices in general. The scientific community can benefit from the increased reflexivity that TDR can bring to science.

Based on these empirical results, we recommend that opportunities for methodologically guided reflection in TDR should be included in the design of research processes. This concerns the different areas of our findings: individual reflection processes as researchers and reflection on disciplinary assumptions and on the role of science and its often hidden normativity. Reflections that target other aspects of the TDR process, such as realistic expectations of TDR's claim to contribute to solving societal problems and the balance between societal and scientific interests in a transdisciplinary research process should be treated separately.

Our findings may have implications for research evaluation. In the introduction, we showed that traditional, disciplinary measurement of 'scientific impact' does not do justice to the effects of TDR. At the same time, the current focus for evaluating TDR is on social effects. With our results, we hope to provide an impetus for broadening research evaluation to the topic of scientific effects of TDR and how they can be captured. Our findings provide some initial indications of dimensions that could be used to structure such an evaluation (see Table 2 for an overview), without being exhaustive. A first step could be to create guidelines with questions for reflection on the topic of scientific effects, similar to what Pearce and Ejderyan (2020) have done with regard to joint problem framing. This approach would direct towards an understanding of evaluation that emphasizes the process of joint learning (formative evaluation). Refining and completing the findings presented in this paper into reflexive guidelines is a task for future research.

The research design and the focus of this study have some limitations. In the empirical data, there were repeated references to institutional challenges to TDR from the higher education system, in academic teaching or in individual departments, potentially resulting in negative effects on the scientific reputation of researchers. However, as our findings focus on the epistemic dimension of TDR, we excluded institutional aspects. The challenges of institutionalizing TDR in the science system have been addressed elsewhere (OECD 2022; Vienni Baptista and Klein 2022) and remain an important aspect for analysing the effects of TDR on science. Further, the presented results must be considered against the background of the selection of the empirical sample. Thus, the statements refer to the German context and to largely established researchers.

One promising aspect of our empirical data that needs to be further explored is the relationship between disciplinary and transdisciplinary research. Without a systematic comparison of the three sub-disciplines, we got the impression that the relationship to TDR differs between the sub-disciplines. We suppose that the disciplinary background and the context of a researcher shape their research practice and understanding of TDR. It would also be plausible that disciplinary constellations influence the emerging scientific effects of TDR and what is perceived as effects. A comparative research design that systematically compares constellations of disciplinary and transdisciplinary research seems innovative and rewarding.

5. Conclusion

In this paper, we investigated effects of transdisciplinary research on science. In an explorative approach, we conducted a qualitative interview study. The results show that transdisciplinary research can generate added value for science by contributing to a better understanding of the scientific problem, improving the quality of scientific insight, and increasing the reflexivity of the researchers involved. We show that TDR can generate positive effects not only for society, which is currently the focus of the discourse, but also for science. We also highlight some challenges associated with the transdisciplinary research mode and barriers that prevent potential scientific effects. These aspects should also be considered in future studies and in research practice.

An empirically informed view on the effects that transdisciplinary research has on science, as we have done here, can contribute significantly to the academic recognition of this research mode and can help to increase the motivation of researchers to engage in methodologically well-founded transdisciplinary processes. TDR deserves more recognition for its contribution to scientific knowledge, and our study might contribute to further strengthening the reputation of TDR within the scientific system. On a more general level, our study adds a new perspective to the debate on broadening the understanding of scientific impact. For the future, we see a need for research on institutional factors that promote or prevent scientific effects of TDR, as well as for empirical studies that systematically examine the scientific effects of TDR at different levels and in different scientific disciplines or contexts.

Supplementary data

Supplementary data are available at *Research Evaluation Journal* online.

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Notes

1. We understand research as a specific social and material practice. Scientific knowledge is thus the product of actions, see Latour and Woolgar (1986); Knorr-Cetina (2002). Research is based on a series of contingent decisions, for example, regarding the choice of instruments or the specification of the problem. Analogously, we consider TDR here as a specific research practice or mode of research.
2. TDR is not the only collaborative research mode that deals with complex societal problems, integrative knowledge production and has transformational intentions. There are large overlaps with research approaches such as participatory research, interactive research, citizen science, joint knowledge production, or action research. In particular, the label of co-production is often used synonymously with TDR, see for example Chambers et al. (2021) and Polk (2015). Especially around the aspects of knowledge generation and scientific effects, there is a large overlap between these research approaches and TDR. We therefore do not differentiate these approaches as long they apply the characteristics mentioned above.
3. For example, some definitions place less emphasis on the participation of non-scientific actors, see Jaeger and Scheringer (2018).

4. This critique is not limited to TDR literature, there is an ongoing discussion calling for societal effects of research to be recognized and assessed (e.g. Reale et al. 2018; Fecher et al. 2021).
5. The analysed projects were all very large projects with many project partners. It is therefore reasonable to assume that specialization has taken place within a consortium, with some scientific partners concentrating on publications and others on interactions with stakeholders.
6. At some points, we make statements specific to a sub-discipline. These are passages in which characteristic features of a sub-discipline have emerged in relation to our research question. However, the focus of our study is not on a comparative perspective between the three sub-disciplines as cases, but on the commonalities that emerge despite the different contexts. Therefore, we do not attempt to present a systematic description of the different ways in which the sub-disciplines understand and relate to transdisciplinary research.
7. In the German academic system, a habilitation is the highest university degree. We are aware that the selection of interview partners with professorships or habilitations may lead to a bias in the results. For example, individuals in such positions face less publication pressure to advance their scientific careers than younger researchers. In addition, senior researchers have a lot of professional experience, which could explain a high degree of reflexivity (see Section 3.3). However, this selection criterion is necessary to obtain respondents who are experienced in both disciplinary and transdisciplinary research, which is central to our research question.
8. Three people coded the data: the two authors of this paper and a student assistant. Intersubjective comprehensibility of coding was achieved through joint discussion of codes and verification of the initial coding by a second person.
9. The change in the understanding of scientific problems through transdisciplinary research described above also influences the research results. The example on the subject of day-care centres (already described in Section 3.1.2) illustrates this argument: The transdisciplinary approach led to the insight that the main object of research is the time spent in the day-care centre and the communication with the kindergarten teachers, and not the transition to the day-care centre. This adaptation also led to different results at the end of the research process.
10. Although individual reflexivity as a personality trait is to some extent a prerequisite for researchers who want to engage in transdisciplinary, experience in transdisciplinary research—as our results show—also contributes to deepening these competencies.

References

Adler, C., Hirsch Hadorn, G., Breu, T., Wiesmann, U., and Pohl, C. (2018) 'Conceptualizing the Transfer of Knowledge across Cases in Transdisciplinary Research', *Sustainability Science*, 13: 179–90.

Belcher, B. M., Claus, R., Davel, R., and Ramirez, L. F. (2019) 'Linking Transdisciplinary Research Characteristics and Quality to Effectiveness: A Comparative Analysis of Five Research-for-Development Projects', *Environmental Science & Policy*, 101: 192–203.

Belcher, B. M., Rasmussen, K. E., Kemshaw, M. R., and Zornes, D. A. (2016) 'Defining and Assessing Research Quality in a Transdisciplinary Context', *Research Evaluation*, 25: 1–17.

Bergmann, M., Brohmann, B., Hoffmann, E., Loibl, M. C., Rehaag, R., Schramm, E., and Voß, J.-P. (2005) *Quality Criteria of Transdisciplinary Research*. With a Foreword by Thomas Jahn. ISOE-Studientexte 13. Frankfurt am Main: ISOE - Institut für sozial-ökologische Forschung.

Bergmann, M., Jahn, T., Knobloch, T., Krohn, W., Pohl, C., and Schramm, E. (2012) *Methods for Transdisciplinary Research. A Primer for Practice*. Frankfurt am Main/New York: Campus-Verlag.

Blum, C., Bunke, D., Hungsberg, M., Roelofs, E., Joas, A., Joas, R., Blepp, M., and Stolzenberg, H.-C. (2019) 'Das Konzept der Nachhaltigen Chemie: Schlüsselfaktoren für den Übergang zu Einer Nachhaltigen Entwicklung', *Sustainable Chemistry and Pharmacy*, 13: 100140.

Bulten, E., Hessels, L. K., Hordijk, M., and Segrave, A. J. (2021) 'Conflicting Roles of Researchers in Sustainability Transitions: Balancing Action and Reflection', *Sustainability Science*, 16: 1269–83.

Chambers, J. M., Wyborn, C., Ryan, M. E., Reid, R. S., Riechers, M., Serban, A., Bennett, N. J., Cvitanovic, C., Fernández-Giménez, M. E., Galvin, K. A., Goldstein, B. E., Klenk, N. L., Tengö, M., Brennan, R., Cockburn, J. J., Hill, R., Munera, C., Nel, J. L., Österblom, H., Bednarek, A. T., Bennett, E. M., Brandeis, A., Charli-Joseph, L., Chatterton, P., Curran, K., Dumrongrojwatthana, P., Durán, A. P., Fada, S. J., Gerber, J.-D., Green, J. M. H., Guerrero, A. M., Haller, T., Horcea-Milcu, A.-I., Leimona, B., Montana, J., Rondeau, R., Spierenburg, M., Steyaert, P., Zaehringer, J. G., Gruby, R., Hutton, J., and Pickering, T. (2021) 'Six Modes of Co-Production for Sustainability', *Nature Sustainability*, 4: 983–96.

D'Este, P., Ramos-Vielba, I., Woolley, R., and Amara, N. (2018) 'How Do Researchers Generate Scientific and Societal Impacts? Toward an Analytical and Operational Framework', *Science and Public Policy*, 45: 752–63.

Enengel, B., Muhar, A., Penker, M., Freyer, B., Drlik, S., and Ritter, F. (2012) 'Co-Production of Knowledge in Transdisciplinary Doctoral Theses on Landscape Development—An Analysis of Actor Roles and Knowledge Types in Different Research Phases', *Landscape and Urban Planning*, 105: 106–17.

Fecher, B., Kuper, F., Sokolovska, N., Fenton, A., Hornbostel, S., and Wagner, G. G. (2021) 'Understanding the Societal Impact of the Social Sciences and Humanities: Remarks on Roles, Challenges, and Expectations', *Frontiers in Research Metrics and Analytics*, 6: 696804.

Fröhlich, G. (1999) 'Das Messen Des Leicht Messbaren: Output-Indikatoren, Impact-Masse: Artekate Der Szientometrie?', in Becker Jörg, and Göhring Wolf (eds) *Kommunikation Statt Markt. Zu Einer Alternativen Theorie der Informationsgesellschaft*. GMD Report 61, pp. 27–38. Sankt Augustin: GMD—Forschungszentrum Informationstechnik GmbH.

Grigorovich, A., Fang, M. L., Sixsmith, J., and Kontos, P. (2019) 'Defining and Evaluating Transdisciplinary Research: Implications for Aging and Technology', *Disability and Rehabilitation. Assistive Technology*, 14: 533–42.

Groß, M. (2011) *Handbuch Umweltsoziologie*. Wiesbaden: VS Verlag für Sozialwissenschaften.

Guimarães, M. H., Pohl, C., Bina, O., and Varanda, M. (2019) 'Who Is Doing Inter- and Transdisciplinary Research, and Why? An Empirical Study of Motivations, Attitudes, Skills, and Behaviours', *Futures*, 112: 102441.

Hansson, S., and Polk, M. (2018) 'Assessing the Impact of Transdisciplinary Research: The Usefulness of Relevance, Credibility, and Legitimacy for Understanding the Link Between Process and Impact', *Research Evaluation*, 27: 132–44.

Hegger, D., and Dieperink, C. (2015) 'Joint Knowledge Production for Climate Change Adaptation: What Is in It for Science?', *Ecology and Society*, 20: 1–13.

Hilger, A., Rose, M., and Keil, A. (2021) 'Beyond Practitioner and Researcher: 15 Roles Adopted by Actors in Transdisciplinary and Transformative Research Processes', *Sustainability Science* 16: 2049–68.

Horlings, L. G., Nieto-Romero, M., Pisters, S., and Soini, K. (2020) 'Operationalising Transformative Sustainability Science Through Place-Based Research: The Role of Researchers', *Sustainability Science*, 15: 467–84.

Hornbostel, S. (1997) *Wissenschaftsindikatoren. Bewertungen in der Wissenschaft*. Wiesbaden: VS Verlag für Sozialwissenschaften.

Jaeger, J., and Scheringer, M. (2018) 'Weshalb ist die Beteiligung von Akteuren Nicht Konstitutiv für Transdisziplinäre Forschung?' *GAIA—Ecological Perspectives for Science and Society*, 27: 345–7.

Jahn, S. (2023) 'Assessing Transdisciplinary Research in Sustainability Science', Thesis. Leuphana University, Lüneburg. <https://pub-data.leuphana.de/frontdoor/index/index/docId/1332> accessed 19 October 2023.

Jahn, S., Newig, J., Lang, D. J., Kahle, J., and Bergmann, M. (2022) 'Demarcating Transdisciplinary Research in Sustainability

Science—Five Clusters of Research Modes Based on Evidence From 59 Research Projects', *Sustainable Development*, 30: 343–57.

Jahn, T. (2008) 'Transdisziplinarität in der Forschungspraxis', in Bergmann Matthias, and Schramm Engelbert (eds) *Transdisziplinäre Forschung. Integrative Forschungsprozesse Verstehen und Bewerten*, pp. 21–37. Frankfurt/New York: Campus Verlag.

Jahn, T., Bergmann, M., and Keil, F. (2012) 'Transdisciplinarity: Between Mainstreaming and Marginalization', *Ecological Economics*, 79: 1–10.

Karcher, D. B., Cvitanovic, C., Shellock, R., Hobday, A. J., Stephenson, R. L., Dickey-Collas, M., and van Putten, I. E. (2022) 'More than Money—The Costs of Knowledge Exchange at the Interface of Science and Policy', *Ocean & Coastal Management*, 225: 106194.

Knaggård, Å., Ness, B., and Harnesk, D. (2018) 'Finding an Academic Space: Reflexivity Among Sustainability Researchers', *Ecology and Society*, 23: 1–11.

Knickel, M., Knickel, K., Galli, F., Maye, D., and Wiskerke, J. S. C. (2019) 'Towards a Reflexive Framework for Fostering Co—Learning and Improvement of Transdisciplinary Collaboration', *Sustainability*, 11: 6602.

Knorr-Cetina, K. (2002) *Die Fabrikation von Erkenntnis. Zur Anthropologie der Naturwissenschaft. Revidierte und Erweiterte Neuauflage*, Zweite Auflage. Frankfurt am Main: Suhrkamp.

Koier, E., and Horlings, E. (2014) 'How Accurately Does Output Reflect the Nature and Design of Transdisciplinary Research Programmes?', *Research Evaluation*, 24: 37–50.

Krainer, L., and Winiwarter, V. (2016) 'Die Universität als Akteurin der Transformativen Wissenschaft: Konsequenzen Für Die Messung Der Qualität Transdisziplinärer Forschung', *GAIA—Ecological Perspectives for Science and Society*, 25: 110–6.

Krohn, W. (2008) 'Epistemische Qualitäten Transdisziplinärer Forschung', in Bergmann Matthias, and Schramm Engelbert (eds) *Transdisziplinäre Forschung. Integrative Forschungsprozesse Verstehen und Bewerten*, pp. 39–67. Frankfurt am Main/New York: Campus Verlag.

Kümmerer, K. (2017) 'Sustainable Chemistry: A Future Guiding Principle', *Angewandte Chemie (International ed. in English)*, 56: 16420–1.

Lam, D. P. M., Freund, M. E., Kny, J., Marg, O., Mbah, M., Theiler, L., Bergmann, M., Brohmann, B., Lang, D. J., and Schäfer, M. (2021) 'Transdisciplinary Research: Towards an Integrative Perspective', *GAIA—Ecological Perspectives for Science and Society*, 30: 243–9.

Latour, B., and Woolgar, S. (1986) *Laboratory Life the Construction of Scientific Facts*, 2. Aufl. Princeton University Press.

Lawrence, M. G., Williams, S., Nanz, P., and Renn, O. (2022) 'Characteristics, Potentials, and Challenges of Transdisciplinary Research', *One Earth*, 5: 44–61.

Lemaître, F., and Le Roux, X. (2021) *Analysis of the Outputs of BiodivERsA Funded Projects: Projects Completed Over 2014-2018. Hg. v. BiodivERsA (BiodivERsA Report)*. <https://www.biodiversa.org/1955/download> accessed 02 Dec 2022.

Lux, A., Schäfer, M., Bergmann, M., Jahn, T., Marg, O., Nagy, E., Ransiek, A.-C., and Theiler, L. (2019) 'Societal Effects of Transdisciplinary Sustainability Research—How Can They Be Strengthened During the Research Process?', *Environmental Science & Policy*, 101: 183–91.

Mayring, P. (2000) 'Qualitative Content Analysis', *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*, 1: Artikel 20.

Nagy, E., Ransiek, A., Schäfer, M., Lux, A., Bergmann, M., Jahn, T., Marg, O., and Theiler, L. (2020) 'Transfer as a Reciprocal Process: How to Foster Receptivity to Results of Transdisciplinary Research', *Environmental Science & Policy*, 104: 148–60.

Nastar, M. (2023) 'A Critical Realist Approach to Reflexivity in Sustainability Research', *Sustainability*, 15: 2685.

Network for Transdisciplinary Research (td-net); Pohl, C. (2022) *Three Types of Knowledge Tool*. Hg. v. td-net.

Newig, J., Jahn, S., Lang, D. J., Kahle, J., and Bergmann, M. (2019) 'Linking Modes of Research to Their Scientific and Societal Outcomes. Evidence from 81 Sustainability-Oriented Research Projects', *Environmental Science & Policy*, 101: 147–55.

Nowotny, H., Scott, P., and Gibbons, M. (2001) *Re-Thinking Science. Knowledge and the Public in an Age of Uncertainty*. Cambridge, USA: Polity Press.

OECD (2022) *Addressing Societal Challenges Using Transdisciplinary Research*. Hg. v. OECD Directorate for Science, Technology and Innovation (OECD Science, Technology and Industry Policy Papers, 88). <https://www.oecd-ilibrary.org/science-and-technology/addressing-societal-challenges-using-transdisciplinary-research_0ca0ca45-en> accessed 19 Oct 2022.

Pärli, R. (2023) 'How Input, Process, and Institutional Factors Influence the Effects of Transdisciplinary Research Projects', *Environmental Science & Policy*, 140: 80–92.

Patton, M. Q. (2002) *Qualitative Research & Evaluation Methods*, 3rd edn. Thousand Oaks: SAGE.

Pearce, B. J., and Ejderyan, O. (2020) 'Joint Problem Framing as Reflexive Practice: Honing a Transdisciplinary Skill', *Sustainability Science*, 15: 683–98.

Pohl, C. H., and Hirsch Hadorn, G. (2007) *Principles for Designing Transdisciplinary Research*. Proposed by the Swiss Academies of Arts and Sciences. München: oekom.

Pohl, C., Klein, J. T., Hoffmann, S., Mitchell, C., and Fam, D. (2021) 'Conceptualising Transdisciplinary Integration as a Multidimensional Interactive Process', *Environmental Science & Policy*, 118: 18–26.

Polk, M. (2014) 'Achieving the Promise of Transdisciplinarity: A Critical Exploration of the Relationship Between Transdisciplinary Research and Societal Problem Solving', *Sustainability Science*, 9: 439–51.

Polk, M. (2015) 'Transdisciplinary Co-Production: Designing and Testing a Transdisciplinary Research Framework for Societal Problem Solving', *Futures*, 65: 110–22.

Popa, F., Guillermin, M., and Dedeurwaerdere, T. (2015) 'A Pragmatist Approach to Transdisciplinarity in Sustainability Research: From Complex Systems Theory to Reflexive Science', *Futures*, 65: 45–56.

Pregernig, M. (2007) 'Impact Assessment of Transdisciplinary Research: In Need of a More Distanced View Wirkungsmessung Transdisziplinärer Forschung: Es Fehlt der Blick Aus Der Distanz', *GAIA—Ecological Perspectives for Science and Society*, 16: 46–51.

Rassenhövel, S. (2010) Performancemessung im Hochschulbereich. Theoretische Grundlagen und Empirische Befunde. Zugl.: Aachen, Techn. Hochsch., Diss., 2009. Wiesbaden: Gabler Verlag/Springer Fachmedien.

Reale, E., Avramov, D., Canhial, K., Donovan, C., Flecha, R., Holm, P., Larkin, C., Lepori, B., Mosoni-Fried, J., Oliver, E., Primeri, E., Puigvert, L., Scharnhorst, A., Schubert, A., Soler, M., Soòs, S., Sordé, T., Travis, C., and Van Horik, R. (2018) 'A Review of Literature on Evaluating the Scientific, Social and Political Impact of Social Sciences and Humanities Research', *Research Evaluation*, 27: 298–308.

Roux, D. J., Nel, J. L., Cundill, G., O'Farrell, P., and Fabricius, C. (2017) 'Transdisciplinary Research for Systemic Change: Who to Learn With, What to Learn About and How to Learn', *Sustainability Science*, 12: 711–26.

Ruppert-Winkel, C., Arlinghaus, R., Deppisch, S., Eisenack, K., Gottschlich, D., Hirschl, B., Matzdorf, B., Mölders, T., Padmanabhan, M., Selbmann, K., Ziegler, R., and Plieninger, T. (2015) 'Characteristics, Emerging Needs, and Challenges of Transdisciplinary Sustainability Science: Experiences from the German Social-Ecological Research Program', *Ecology and Society*, 20: 1–13.

Schäfer, M., Bergmann, B., and Theiler, L. (2021) 'Systematizing Societal Effects of Transdisciplinary Research', *Research Evaluation*, 30: 484–99.

Vienni Baptista, B., and Klein, J. T. (eds) (2022) *Institutionalizing Interdisciplinarity and Transdisciplinarity. Collaboration across Cultures and Communities*, 1st edn. New York, London: Routledge; Taylor & Francis Group.

Vilsmaier, U., Engbers, M., Luthardt, P., Maas-Deipenbrock, R. M., Wunderlich, S., and Scholz, R. W. (2015) 'Case-Based Mutual Learning Sessions: Knowledge Integration and Transfer in Transdisciplinary Processes', *Sustainability Science*, 10: 563–80.

Wamsler, C. (2017) 'Stakeholder Involvement in Strategic Adaptation Planning: Transdisciplinarity and Co-Production at Stake?', *Environmental Science & Policy*, 75: 148–57.

Weingart, P. (2010) 'A Short History of Knowledge Formations', in Frodeman Robert, Thompson Klein Julie, and Mitcham Carl (eds) *The Oxford Handbook of Interdisciplinarity*, pp. 3–14. Oxford: Oxford University Press.

Wendt, B., Böschen, S., Barth, T., Henkel, A., Block, K., and Dickel, S. (2018) '"Zweite Welle"? Soziologie der Nachhaltigkeit—von der Aufbruchsstimmung zur Krisenreflexion', *Soziologie und Nachhaltigkeit*, Sonderband, 1: 1–23.

Wittmayer, J. M., and Schäpke, N. (2014) 'Action, Research and Participation: Roles of Researchers in Sustainability Transitions', *Sustainability Science*, 9: 483–96.

Wright, M. T., Allweiss, T., and Schwersensky, N. (2021) *Partizipative Gesundheitsforschung. BZgA-Leitbegriffe: Partizipative Gesundheitsforschung (letzte Aktualisierung am 04.01.2021)*. Hg. v. Bundeszentrale für gesundheitliche Aufklärung.

Zierhofer, W., and Burger, P. (2007) 'Transdisziplinäre Forschung—Ein Eigenständiger Modus Der Wissensproduktion? Problemorientierung, Wissensintegration und Partizipation in Transdisziplinären Forschungsprojekten', *GAIA—Ecological Perspectives for Science and Society*, 16: 29–34.

Zscheischler, J., Rogga, S., and Lange, A. (2018) 'The Success of Transdisciplinary Research for Sustainable Land Use: Individual Perceptions and Assessments', *Sustainability Science*, 13: 1061–74.