Societal effects of transdisciplinary sustainability research—How can they be strengthened during the research process?

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ABSTRACT

Transdisciplinary sustainability research aims to mitigate or to solve complex societal problems and advance the production of scientific knowledge. Reflexive approaches to transdisciplinary research processes are outlined to systematically strengthen the potential for societal effectiveness. So far, it is rare to find empirically based analyses of the links between the quality of the research process and the methods applied on the one hand and the effects achieved on the other.

This paper thus addresses the issue of heightening the societal effects of transdisciplinary sustainability research. The objective is to explore ways of consciously promoting societal effectiveness in transdisciplinary research. We argue that these possibilities evolve at the intersection between the general project framework and an adaptive shaping of transdisciplinary research processes. A reflexive approach of this kind proactively considers the dynamics of interests and concerns, roles and responsibilities, the collaboration culture within a project, and the connectivity to the context of action addressed. Its deployment presupposes an appreciation of the basic conditions, i.e. the historical development of the respective problem, the heterogeneity of actors involved, the general environment and, finally, the funding conditions.

1. Introduction

1.1. In support of the production of transdisciplinary knowledge

During the last decades, sustainability issues have attracted increasing attention in science (e.g. Hirsch Hadorn et al., 2008; Lövbrand, 2011; Spangenberg, 2011; Lang et al., 2012; Brandt et al., 2013; Jahn, 2015). This is accompanied by an ongoing debate about the capacity of science (and the academic system) to provide knowledge that addresses urgent societal challenges appropriately (Jantsch, 1972; Hirsch Hadorn et al., 2008; Mittelstrass, 2011; Jahn et al., 2012; Krohn et al., 2017). In this regard, existing literature emphasises the need for a change in how knowledge is produced to be able to react to complex, intertwined problems in an integrated manner (Funtowicz and Ravetz, 1993; Gibbons et al., 1994; Nowotny, 1999; Nowotny et al., 2001; Jasanoff, 2004; Jahn et al., 2012; Krohn et al., 2017; Klenk and Meehan, 2017). Within this debate, some of the relevant key concepts are post-normal

science, mode 2 research, co-production of knowledge, and transdisciplinarity. Despite different epistemological backgrounds in the debate, there is a shared vision of "breaking free of reductionist and mechanistic assumptions about the ways things are related, as how systems operate, and the expectation science delivers a single "best" solution or final answers" (Klein, 2014: 72).

We further refer to the terms *transdisciplinarity* (TD) as a research mode and *transdisciplinary research* (TDR) as the practice of TD (Jahn et al., 2012: 8f.). It is the ultimate goal of TD to relate scientific capacities (for example, knowledge on certain issues, analytical methodologies or scientific infrastructures) to real-world problems and other forms of knowledge to outline options for the mitigation or solution of such problems. Thus, TDR aims at both societal and scientific progress. The main resources supporting integrative attempts in TDR are integration methods that relate scientific to extra-scientific knowledge (Bergmann et al., 2012; Polk, 2015; Defila and Di Giulio, 2015) and the capacity to reflect on values, assumptions and power structures that

shape research objects and the organisation of (transdisciplinary) science (Popa et al., 2015). *TDR processes* are problem-oriented and, inter alia, characterised by participatory problem definition, method-driven knowledge integration and differentiated preparation of findings for practice and science (Hirsch Hadorn et al., 2008; Carew and Wickson, 2010; Pohl, 2011; Jahn et al., 2012).

This paper is thus concerned with fostering the societal effects of transdisciplinary sustainability research. The aim is to explore how to proactively generate potential for societal effectiveness in TDR via the adaptive shaping of TDR processes. In the following, we will introduce our understanding of the societal effects of TDR (Section 1.2). Based on an empirical analysis of completed transdisciplinary projects in the wider field of sustainability research (Section 2), the main part (Section 3) describes the synthesised findings on the relevance of framework conditions (Section 3.1) and how to approach them in TDR processes (Section 3.2). The overarching results are summarised and discussed in Section 4. We conclude with further research needs (Section 5).

1.2. Understanding societal effects of TDR

Recommendations and guidelines exist for dealing with the challenges of conducting TDR (e.g. Bergmann et al., 2005; Defila et al., 2006; Pohl and Hirsch Hadorn, 2007; Bennett et al., 2010; Bergmann et al., 2012; Lang et al., 2012; Binder et al., 2015; Gaziulusoy et al., 2016; Frodeman et al., 2017; Pohl et al., 2017). Furthermore, attempts have been made to define indicators for 'successful' TDR and quality criteria for research processes (Klein, 2006; Carew and Wickson, 2010; Wolf et al., 2013; Belcher et al., 2015; Jahn and Keil, 2015; Hansson and Polk, 2018; Maag et al., 2018; Schneider and Buser, 2018; Wyborn et al., 2018; Hitziger et al., 2019). Most authors agree on the lack of clear causal relationships between the research process, its results and the effects elicited (Walter et al., 2007; Bornmann, 2013; Kaufmann-Hayoz et al., 2016; Krainer and Winiwarter, 2016). Effects are considered to emerge from complex and non-linear communication processes that are influenced by further actors (e.g. knowledge brokers or intermediaries), situational factors or further intermediate steps (Litfin, 1995; Walter et al., 2007; Meyer, 2010; Kaufmann-Hayoz et al., 2016; Krainer and Winiwarter, 2016; Belcher and Palenberg, 2018; Maag et al., 2018). Often, there is a considerable time lag between a TDR project and observable societal changes. Due to further influences, the attribution of certain effects to a specific research project remains a major challenge (Bornmann, 2013; Krainer and Winiwarter, 2016). There is an ongoing debate about methods able to grasp this complex interplay of several factors (Meagher et al., 2008; Boaz et al., 2009; Wiek et al., 2014; Belcher and Palenberg, 2018; Hansson and Polk, 2018).

Acknowledging this debate, in our study we place emphasis on *generating potential for effective TDR* by addressing critical points during the research process instead of suggesting that certain research activities will lead directly to specific effects.

When it comes to differentiation in results and effects, and the differences between forms and levels of societal effects, a variety of terms and definitions are used, in some cases with the same terms meaning different things. The lack of clarity and consistency in definitions is also a characteristic of discourses on evaluation (Kaufmann-Hayoz et al., 2016; Belcher and Palenberg, 2018). For example, there is no shared understanding of whether "products" (e.g. academic or non-scientific publications) are to be categorised as "output" or "effect". With regard to effects, in the discourse on development evaluation the term "outcome" is used for short-term and medium-term effects and the term "impact" for longer-term changes (OECD - Organisation for Economic Co-Operation and Development, 2010), while the same terms are used vice versa in some publications concerned with evaluating the effects of research (ESRC, 2009).

For our study, we decided on the term *societal effects* in accordance with other authors (e.g. Walter et al., 2007; Wiek et al., 2014): in our

heuristic, we distinguish between different orders of societal effects depending on their temporal and spatial distance to the research processes and the results they generate. We refer to first-order effects as those that occur within the duration and spatial scope of a project and use the term second-order effects for changes that occur within the immediate temporal or spatial context of the project. For us, the term third-order effects denotes changes beyond the temporal or spatial context of the project, for instance processes of institutional consolidation (in the same context but with a longer time lag) or imitation (in other spatial contexts). While it might be possible to trace links between project activities or results and first-order effects, this analysis becomes more challenging for the attribution of second- and third-order effects, due to the additional influencing factors mentioned above. CIDA (2008) provides a helpful differentiation in this context: sphere of control (within the project), sphere of influence (beyond the project boundaries) and sphere of concern (no direct influence, contribution to a chain of events leading to observed change).

In the literature on TDR or research evaluation, various forms of effects are considered, which different terms are used for. We derived four categories for societal effects from various authors (Walter et al., 2007; ESRC, 2009; Wiek et al., 2014; Mitchell et al., 2015; Kaufmann-Hayoz et al., 2016), which we used as explorative categories for the analysis of the case studies: learning processes, capacity building, network effects and improvement of the situation. The latter category encompasses in our understanding structural changes and decisions or actions in the public sphere as opposed to on an organisational level (cf. also Wiek et al., 2014).

2. Empirical background

The paper presents the synthesis of the 3-year collaborative research project "TransImpact – Effective Transdisciplinary Research". The main question posed by TransImpact was whether the application of certain practices or methods in transdisciplinary projects was able to foster societal (and scientific) effects. To address this question, we conducted an empirical assessment of several case studies and synthesised the results.

From a database established in TransImpact, 16 out of 75 finalised TD projects were selected for a detailed case study analysis (see Table 1 for the selected case studies). The set of case studies assured a high diversity of (a) topics in sustainability research and neighbouring fields, (b) funding bodies (public/private; EU/national/regional), (c) lead institutions (e.g. university/non-university), and (d) research formats and methods. For our analyses, the 16 case studies were grouped into four thematic clusters focusing on problem definition, participation, knowledge integration, and transferability. The grouping of case studies was based on publicly available project information and a first introductory interview with the respective coordinators. Criteria for assigning a case-study project to one of the thematic clusters were: (a) the topic of the cluster was explicitly addressed in the case study (or difficulties with addressing it had been stated), (b) the project was expected to deliver sufficient documentation as a basis for the case study analysis and fruitful discussions during the analysis, and (c) coordinators were interested in the cluster topic.

A multi-step approach was conducted consecutively from June 2016 to September 2018 in each thematic cluster (see Appendix A in Supplementary materials for more details):

1) Research in each cluster was conducted based on preliminary conceptual assumption, using a *case study approach*. Project-specific reports, publications and supporting questionnaires were analysed regarding (a) the specific framework conditions of these cases (b) the methods and procedures applied, in particular with respect to the cluster topic, (c) the results and products (academic and non-academic publications, products beyond publications, networking, presentations, etc.), and (d) any positive intended and unintended

Table 1
Clustered overview of case studies selected for TransImpact.

No	Lead Partner	Topic	Funding Scheme	Approx. duration
Cluster problem definition: The description of the everyday life problems to be addressed (joint problem framing) shall impact positively on the potential for societal effectiveness generated via TDR. Research questions: which parameters have to be considered and which methodological options exist to foster potential for societal effectiveness already during the phase of problem description and project planning?				
I	Non-university research institution	Land management and regional economies	National research ministry	3 years (plus follow-up project)
II	Non-university research institution	Material optimisation and recycling	EU research framework programme	3.5 years
III	University	Local supply in rural areas	European Regional Development Fund	4 years (incl. 1 year pre-phase)
IV	Non-university research institution	Water supply & consumption	Contract work (industry)	2 years
Cluster participation: Participation of actors from business, civil society, and politics offers the possibility to comprehend the problem under review in its full scope and complexity. Participation shall be a key factor for societally relevant TDR and a successful implementation of its findings. Research question: with which methodological design can participative processes strengthen effects of TDR?				
V	Non-university research institution	Climate adaptation (various fields)	National research ministry	5 years (plus follow-up projects with some of the initial partners)
VI	University, but interdisciplinary faculty	Hospital management	National research ministry	6 years funded, 3 further years with self-funding in the beginning and the end
VII	Non-university research institution	Education for sustainable development	National research ministry	2 years
VIII	Non-university research institution	Climate mitigation (consumption)	National research ministry	3 years
Cluster knowledge integration: In order to solve complex societal problems, the knowledge of various scientific disciplines has to be collated and linked with knowledge and experiences from everyday life. Successful knowledge integration shall be important for the effectiveness of TD research. Research question: How can knowledge integration be carried out methodologically that findings from research will be effective?				
IX	University	Nature protection	National environmental ministry	5,5 years (incl. pre-phase)
X	University	Water management for water supply	National research ministry	4 years
XI	University	Climate adaptation (water management)	National research ministry	3,5 years (incl. pre-phase)
XII	Non-university research institution	Energy transition	Regional environmental ministry	1 year
Cluster transferability: It was supposed that TDR can be particularly effective if it generates findings that are relevant beyond the individual case under review and can be adapted in other spatial or thematic areas. Research question: How can transferability be anchored within the research process?				
XIII	University, but interdisciplinary institute	Disaster protection	National research ministry	3 years
XIV	University	Public health	Miscellaneous	Series of follow-up projects from 2005 onwards
XV	University	Urban agriculture	National research ministry	3 + 5 years
XVI	Non-university research institution	Urban-rural land use conflicts	Subnational environmental ministry	3 years

effects realised, as well as negative unintended effects. These analyses were summarised in case descriptions. Within the case study approach, categorisation of different effects along the three orders and four categories developed in Section 1.2 had a mainly heuristic function (how to ask for different effects). The main interest of the study was not in assessing the (societal) effects itself but to understand which procedures and efforts undertaken in the projects might be connected to them. Preliminary conclusions in this regard were summarised across the four case studies in each thematic cluster.

2) In a second step, these preliminary conclusions were discussed within two-day *project forums,* respectively. These forums supported in-depth discussions with participants from the case studies with respect to one of the focal topics. Two to five partners from each case-study project participated, one being the coordinator and one at least a practitioner. The discussions in the four project forums were documented to allow preliminary generalisations by identifying key issues for each thematic cluster.

3) For each cluster, the generalised results were presented in a validation platform for *discursive validation* with further TD experts to enrich and validate the generalised results of the project forums. The main aim was to obtain feedback on the preliminary results from experienced TD researchers to balance the limited data set of 16 case studies analysed in TransImpact, and to broaden expertise on the conceptual and theoretical underpinnings of TD and its praxis. Critical remarks were invited and incorporated into the reflective and iterative preparation of the results after the event.

4) The results for each cluster included cluster-specific requirements for supporting the potential for (societal) effectiveness and a collection of methods and procedures addressing these requirements. The results were documented and published via the online platform www.td-academy.org (so far only in German).

Overall, the empirical approach was qualitative and explorative, with strong participative elements (interactive dialogue with partners of the analysed case studies from science and practice as well as with further TD experts), and taking a conceptual lead from the current state-of-the-art TD discourse. Appendix A in Supplementary materials describes the empirical approach within TransImpact in more detail. The paper at hand discusses the insights of the case study assessment from an overarching perspective and summarises them across the thematic clusters.

3. Results

For the synthesis of our empirical study, we summarised the detailed insights into fostering and hindering conditions for societal effects in TDR across case studies and thematic clusters. The empirical analysis revealed that societal effects can evolve from both the activities carried out in adequate TDR processes producing relevant results and the framework conditions in which TDR is embedded. Major framework conditions of relevance have turned out to be historicity, the heterogeneity of actors, the general environment, and funding conditions (see Section 3.1). For adaptive shaping of TDR processes that foster potential for societal effects, we have identified five major fields: problem relevance, connectivity, roles & responsibilities, interests & concerns, and collaboration culture (see Section 3.2.).

3.1. Relevance of framework conditions

A major result arising from the empirical analysis of 16 case studies was that framework conditions in which TDR is embedded are of high relevance in fostering – or hindering – (societal) effectiveness in TDR. Initially, framework conditions are to be seen as a given, with limited possibilities to influence them. They may be fairly stable (e.g. biogeophysical factors), but may also be dynamic (e.g. political majorities, urban development). In our analysis, it was possible to identify four

Table 2
Shaping TDR processes: problem relevance.

Recommendation	Target	Example methods
Include knowledge about the problem	For better connectivity and usability of the findings among practitioners, it is important to understand the context of a problem, its genesis and earlier developments. Practical experiences in the problem context are as important as scientific contexts.	Issue mapping or systemic problem structuring
Understand the context of action	For generating practice-oriented knowledge that feeds into applicable recommendations, the facilitation of integrative and participative processes in TDR has to be oriented towards the context of action of societal (practice) partners. This is about both staying in relation with the societal problem and understanding the scope of action in societal reality.	Facilitating understanding through (qualitative) interviews with, for example, intermediaries from different societal sectors
Review actor composition	For effective TDR, the relevance of the involved actors for the societal problem at stake has to be clarified at the start and reconsidered during the research processes. Actors who are able to play a supportive role are just as important as those who are expected to be reluctant.	Iterative actor/stakeholder analysis or constellation analysis
Explicate and justify selection (exclusion) of knowledge bases	TDR discusses not only *how* to integrate different kinds of knowledge but also *which* knowledge to select (or to neglect) in the process of knowledge integration. By justifying such decisions with regard to the problem under review it is possible to facilitate the research processes that address the initial problem and thus potentially increase effectiveness.	Dialogue-oriented methods of knowledge integration

crucial framework conditions across the above-mentioned four thematic clusters:

Historicity emphasises the history of the problem at hand and includes, for example, the causes and dynamics behind the problem under consideration in a transdisciplinary project, the previous relationships between actors (collaborative, conflicting, non-existent), or previous projects dealing with the problem. The inference here is that it makes a difference for generating potential for societal effects whether there is an (accessible) history for building upon existing discussions, ideas or collaborations. In turn, an existing history could also have negative implications, for example if trust was lost during earlier collaborations, or if previous (technical or infrastructural) implementations are path-dependent and hardly open to transformations. During our analysis it transpired that societal effects of TDR – often conducted in projects within certain time and spatial scales – are not only bound to the earlier developments but also to existing possibilities of sustaining follow-up activities (cf. Section 4.2).

The case-study partners also emphasised how crucial it is to be aware of the *heterogeneity of actors*. At the beginning of the projects, some of the case-study partners assumed that merely acknowledging the differences between societal and scientific actors would be sufficient to accord any divergence in terms of logic and reasoning or interests and expectations. However, some partners reported that during project implementation the differences within those main groups were sometimes larger than between societal and scientific actors. For instance, the from a scientific perspective seemingly homogeneous group of non-scientific actors can differ greatly in terms of dealing with project tasks or perceiving functions and roles if we consider their various backgrounds in administration, business or NGOs and the different resources available to them. This aspect is often underestimated but is relevant when dealing with the idea of effective TDR. Such differences can be considered a basic parameter, since different organisational settings and institutional mind-sets cannot be changed in short periods of time and must be taken into account during project planning.

Environment is the broadest framework condition and describes the relevant wider context of the problem at hand. It complements historicity and includes situational factors such as current social discourses, legislation, exceptional phenomena (e.g. Fukushima for energy system transformation projects), or the current state of research. Thus, the environment captures the wider context of a specific TDR activity. The challenge is to make the problem-related specifics accessible for TDR, particularly when starting research in a new or poorly understood environment. The environment shapes the possibilities and limits for generating potential effectiveness in TDR in two ways: first, taking environment and its inherent dynamics into account during the phase of

transdisciplinary problem definition can affect the conception and planning of the project. Second, various characteristics of the environment (e.g. changing political power relations or legislation) can change to such an extent that the objectives addressed are called into question to a significant degree—and should be revisited for possible adaptations during the course of the project.

Funding conditions are specifics that frame the leeway of a defined project to act in several ways: The research agenda, additional expectations on the part of funding bodies, and the resources provided by a funding programme or a specific tender set the scope of action for a project. This is true for the problems to be targeted and the structure of the project (team, organisation, etc.), but also for its potential effectiveness. The conditions set by the funding body, i.e. the amount of funds, the contract formats, its demands regarding proposals/tenders and the demands made during the research process (e.g. flexibility for changes) can have a positive or negative influence on the potential effects of TDR (cf. Newig et al., 2019/in this issue).

It proved to be important to focus on external framework conditions when deciding how to foster the societal effects of a specific TDR activity. The way they are described above shows that one main challenge for effective TDR is to recognise and to understand the framework conditions of a project in order to deal with them productively. The relevant aspects of proactively promoting societal effects as a result of TDR are discussed in the next section.

3.2. Adaptive shaping of TDR processes to foster societal effects

In our empirical analysis of 16 case studies, we revealed five major fields in which a project team can engage to achieve the adaptive shaping of TDR processes: problem relevance, connectivity, roles & responsibilities, interests & concerns, and collaboration culture. In the following, we present the detailed recommendations we derived from the considerations of these fields. The example methods mentioned in the tables are collected in Appendix B in Supplementary materials, which provides relevant literature for these methods.

Some of the partners in the case studies suggested that their success—in terms of realising desirable effects—was closely related to their ability to directly address problems perceived as urgent, involve stakeholders, and take sufficient account of their perspectives. Thus, we compiled under *problem relevance* (Table 2) all aspects that facilitate a better understanding of the problem situation and the application context. This also relates to the framework condition 'environment'. This is supported by the general assumption that TDR has to address a real-world problem, redefine it as a transdisciplinary problem and generate integrated knowledge to explore conceivable problem

Table 3
Shaping TDR processes: connectivity.

Recommendation	Target	Example methods
Identify relevant actor groups for co-facilitating societal effects (e.g. intermediaries)	Along with the identification and review of actor composition (see above), effectiveness of TDR can be strengthened via an early assessment of those (societal or scientific) groups or individuals who can influence achieving expected effects positively or negatively.	Iterative actor/stakeholder analysis or constellation analysis
Addressing new contexts with potential for transfers	For providing the gained knowledge and results beyond the immediate project context, it is central to identify contexts with potential for transfer. In order to address these new contexts, a range of activities with different levels of actor involvement from the context of origin and the new contexts is possible. Within the new context, knowledge and results from the original TDR project are being modified, enriched, and adapted. The processes of appropriation within new contexts can be supported by actors from the original context.	Systemic analysis of transfer potential
Provide results adequately	While most of the recommendations address the structuring and facilitation of processes, the results and products they generate should also be taken into account. At the latest when it comes to transfer, they must receive greater attention. The knowledge generated is incorporated into the results and products – and should be comprehensible for those who did not participate in the TDR processes. In this context, target-group- specific preparation and presentation of results plays a major role.	Morphological analysis, usability tests or similar feedback formats

solutions (Hirsch Hadorn et al., 2008; Jahn et al., 2012).

Connectivity (Table 3) refers to the challenge posed by the aim of effective TDR to account for constraints on the actions of relevant stakeholders or on further target groups in applying the results. Results and products should not only meet needs and expectations of current target groups, but address contexts and actors that could (co-)facilitate societal effects of TDR, for example through mediation and transfer (cf. also Hoffman et al., 2019/in this issue).

The recommendations regarding *roles & responsibilities* (Table 4) reflect that major failures in the case studies—in terms of not being effective—were due to a lack of clarity in the roles, functions and tasks of each partner, which may change in different phases of the project. An explicit definition of roles and their fulfilment thus seems vital. This is primarily up to project coordinators, but is also a matter for individual and team reflection. With regard to roles, our analysis also points out two roles that are very important for effective TDR: the responsibility for knowledge integration and the role of intermediaries in supporting the transfer of knowledge to the field or comparable problem contexts.

Furthermore, TDR is often embedded in plural normative frameworks, (particular) interests and concerns. Along with the lack of clarity in roles, the case studies showed that a lack of transparency about the underlying *interests & concerns* (Table 5) also put TDR at risk of not being effective. Hidden agendas or unshared objectives prevent generating potential for effectiveness in TDR.

Finally, the case-study partners pointed out several aspects that can be summarised as a positive and inspiring collaboration culture (Table 6) very conducive to effectiveness. They stated, for example, the significance of informal settings for backing structured collaboration.

4. Discussion

4.1. Limitations of the study

The empirical approach (cf. Section 2) had certain methodological limitations to obtain reliable and revealing insights. Statements from the case-study partners about the completed projects had to be handled with care, since their memories fade and are overlaid by recent experiences (a typical methodological problem of ex-post analyses). In

Table 4
Shaping TDR processes: roles & responsibilities.

Recommendation	Target	Example methods
Clarify roles	Determining the responsibilities, functions and tasks of the actors involved in the early phase of a project is not only good practice in project management but also the basis for potential effectiveness by rendering the individual contributions transparently. Clarifying the coordinator's role should be part of this process.	Co-writing of proposals or the application of a tandem principle to project leadership to make mutual expectations explicit
Observe role fulfilment	It is not enough to merely clarify and agree on roles. It is also important to observe the ways in which they are (not) fulfilled in the course of TDR. A reflexive approach towards assigning roles (individually or institutionally) strengthens potential effectiveness. Again, reflection of role fulfilment on the part of the coordinator should be part of the process. This is of utmost importance in participatory processes, but also in the preparation of transfer, in particular regarding the role of intermediaries.	Iterative SWOT analysis of the collaboration, with continuous feedback processes
Determine procedures and responsibilities for knowledge integration	Knowledge integration is at the core of TDR; jeopardising these processes means putting the overall quality of TDR projects and their (applicable and effective) results at risk. Thus, reasonable efforts in knowledge integration (not only as a cognitive but also a social and communicative process (see Table 6) are important for the effectiveness of a project. An agreement on procedures of knowledge integration and a clear nomination of a competent team member or a group as responsible for them support the integration efforts.	
Support intermediaries	In attempting to generate transfer potential, it is important to identify the relevant groups or individuals able to mediate knowledge and results of a project. These actors can be supported, for example with relevant material, network contacts or background information. (see also Table 3)	Dialogue-oriented collaboration formats

Table 5

Shaping TDR processes: Interests & concerns.

Recommendation	Target	Example methods
Disclose interests	The dominance of (particular) interests can hinder the effectiveness of TDR. For this reason, the interests of the actors involved in a project should be made explicit, discussed and taken into account at an early stage.	Integrative formulation of a hypothesis to disclose content-related arguments that originate in interests
Observe dynamics of interests	For effective TDR processes, the interests of the scientific and societal actors involved and how they may change during the project course should be examined for their potential to hinder or foster the success of a project (relates strongly to "understanding the context of action" and "role fulfilment", see above).	Multi-stakeholder discussion group

addition, the case-study partners only represented part of the respective project teams behind the case-study projects. Moreover, the analysed documents were rarely written with the intention of presenting insights into conditions for the effectiveness of TDR. Thus, they had to be re-interpreted by the TransImpact team. To a certain extent those limitations could be rectified by acquiring feedback on the results and conclusions during the project forums and validation platforms.

Most of the participants in the project forums were familiar with the TD discourse and the concept of 'ideal' TDR. Despite their pre-existing experience, the case-study partners often had difficulties in appraising the relevance of concrete procedures or methods for certain effects. We conclude that TDR projects often have to cope with unexpected events requiring intuitive action and expertise based on tacit knowledge.

These limitations of data in working with the case studies were compensated for by the involvement of further TD experts during the validation platforms. They have enriched our findings with further experiences and expertise from both TD theory and TDR practice.

4.2. Relevance of the results for the discourse on TDR

The aim of our study was to identify approaches that strengthen the potential societal effectiveness of TDR. Based on an empirical study with 16 case studies, we identified framework conditions that may foster or hinder societal effects (Section 3.1) and pointed out relevant approaches for shaping TDR processes to generate potential for effectiveness in a proactive way (Section 3.2). The main contribution of our research to the existing expertise and consensus in the TD discourse consists of recommendations for a systematic approach to shaping TDR processes with regard to bringing about (intended) societal effects during the whole research process, incl. recognising the relevance of external framework conditions. The overarching structure of our findings sets the main fields of shaping TDR process and the external framework conditions into a new relation to each other.

Fig. 1 summarises the major findings on fostering potential for effectiveness in TDR described above (Section 3). The main connection between the framework conditions and the adaptive shaping of TDR processes is keeping the reference of the problem defined in the project

to the complex societal problem (*white arrow in* Fig. 1). The insights of the case studies analysis emphasise the connectedness between framework conditions and TDR processes and in so doing shows that effects of TDR can rarely be facilitated in isolated projects, since this ignores the fact that transformation processes always build on historical development and possibilities to sustain or continue.

Based on the results described above, we can draw general conclusions for fostering societal effectiveness in TDR. In doing so, we reflect on the overarching relations between framework conditions and shaping TDR-processes in terms of fostering potential for societal effects.

(a) Early engagement with effectiveness: The most important insight is that the entire project team (scientific and societal partners) must engage early with the societal effects they wish to bring about. Such an undertaking is anything but simple – especially at a very early stage of TDR, i.e. often even before a formal project starts. The argument underpins the assumption that formed the basis for the heuristic of societal effects (Section 1.2): such effects emerge from complex inter-dependencies between research processes *and* the results they produce. The anticipation of intended effects calls for reciprocal interaction between the tasks of identifying the real-world problem at stake, recognizing the external framework conditions, building a team and formulating a joint and transdisciplinary problem description. Compared to existing recommendations for facilitating TDR processes in literature (e.g. Pohl and Hirsch Hadorn, 2007; Lang et al., 2012), even more effort is expected in the early phase of TDR. This means going beyond mere reflection on a problem and its history (see Section 3.1) to consider supportive actors, possible follow-up activities and expected effects: while setting up the project or in the very first collaboration phase, a vision could be created for possible follow-up to the TDR processes initiated. This also means distinguishing between different forms and orders of effects (cf. Section 1.2) and between objectives, results and effects (without assuming a clear linear relationship between them). Although our case studies rarely carried out this collaborative exercise, the project forums revealed that case-study partners estimate a higher potential for societal effects when they are considered early in TDR projects. Our results also indicate synergy effects: an early

Table 6

Shaping TDR processes: collaboration culture.

| Task	Target	Example methods
Facilitate knowledge integration socially & communicatively	Since knowledge integration processes provide several impulses for strengthening effects in TDR, these processes should be facilitated – and this goes beyond providing methods of integration and appointing responsible team members (see above). A stimulating working atmosphere and mutual understanding within the project team are important for effective knowledge integration and should be consciously cultivated. Thus, the challenge is to understand integration as a cognitive *and* social and communicative process.	Combining structured integration methods with informal settings
Create occasions & opportunities for knowledge integration	For effective knowledge integration, concrete occasions should be planned for explicating, exchanging and bringing together the knowledge of project partners and stakeholders using different methods. It is also important to be open to new opportunities for knowledge integration arising during the process.	Intersection workshops with external moderation and integrative and communicative formats (world café, focus groups, etc.)
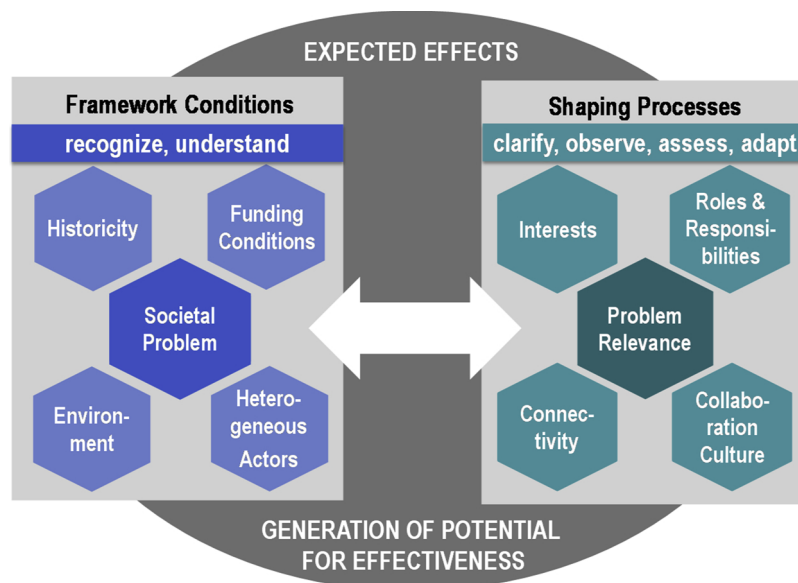
Fig. 1. TransImpact approach to foster potential for effectiveness in TDR (own illustration).

engagement with the expected effects provides a preliminary basis for developing strategies regarding participation, integration or transfer as major pillars of TDR and for the reflection of processes, results and products during the project. Thus, these main pillars are not to be understood as consecutive processes and instead should be seen as intricately linked and mutually dependent in terms of generating societal effects in TDR. This is important, since our empirical insights show that effects cannot be 'planned' entirely. The case studies confirmed previous findings cited in Section 1.2 stating that the generation of effects at a greater spatial, temporal or thematic distance to a transdisciplinary activity are subject to multiple influences that cannot be foreseen and controlled by a single project. At the same time, partners of the case-study projects reported unexpected (often positive) effects such as learning loops, or the uptake of an idea developed in another practical context. This confirms that effects do not necessarily follow the final project results and leads to our finding (b).

(b) Processes and results are equally important: The recommendations for adaptive shaping of TDR processes discussed in Section 3.2 create leeway to evolve potential effectiveness by facilitating adequate processes and producing relevant results. In this context, it was surprising that the seemingly clear difference between processes and results could not be clearly attributed to the effects of the case studies. Our case studies show neither that results are more responsible than a high-quality process for generating societal effects, nor vice versa. Our conclusion is that research processes and their results are closely intertwined when it comes to generating potential for effectiveness. However, in line with the literature on societal effects (see Section 1.2), our results confirm that learning effects, capacity building and network effects are more closely related to process quality. With regard to transferability, we also clearly show that adequate preparation of results on its own is not sufficient to ensure their uptake. Communication and mediation on the one hand, and active appropriation on the other hand are decisive (cf. Nagy et al., 2019/in this issue for more details on our findings regarding transferability).

(c) Adaptive shaping: clarify, observe, assess, adapt: The results on adaptive shaping of TDR processes show the importance of reflecting on interests, roles, connectivity, and collaboration culture within a project. In this regard, we provided an overview and recommendations in Section 3.2. Clarification, observation, assessment and adaptation are general activities for maintaining reflectivity throughout TDR processes. For example, reflecting on the root of the problem could reveal a conflict of interests as a major driver for a problem situation. The

approach of a transdisciplinary project should reflect on interests and make them explicit from the start and observe dynamics of ongoing processes; changes have to be assessed. To derive consequences for adaptive shaping of TDR processes keeping the reference of the problem defined in the project to the complex societal problem should be considered. Sometimes, it might be necessary to change the set of collaborators or the reformulate the project aims or expectations regarding (societal) effects. This illustrates the pattern behind the idea of adaptive shaping of TDR processes to foster potential effectiveness and acknowledges the challenge of implementing processes in a straightforward way. Our results provide guidelines for the adaptive shaping of TDR processes, which we regard as a beneficial complement to results from several authors on TDR practice (e.g. Defila et al., 2006; Pohl and Hirsch Hadorn, 2007; Belcher et al., 2015; Pohl et al., 2017). The recommendations presented in Section 3.2 are rather structured according to areas of prime importance throughout TDR processes than according to the three project phases as developed by Jahn et al. (2012).

(d) Joint preliminary understanding of project's approach and aims: Adaptive shaping of TDR processes as discussed above requires a shared (preliminary) understanding of the project's approach, organisation (integration, participation) and outreach (effects, transfer) from the beginning and among all partners. This preliminary understanding is then specified in the course of the project and is a well-known approach for conducting TDR (cf. Section 1). Nonetheless, analyses in our case studies have shown that the potential for effectiveness diminishes if too much background knowledge and too many assumptions remain implicit, i.e. if there is a lack of clarification or if receptivity of results is neglected.

5. Conclusions and further research needs

This paper systemises arguments and recommendations for strengthening the capacity for societal effects in TDR (see also the documentation of the results in German on www.td-academy.org for more details in this respect) Fostering societal effects in TDR is a continuous endeavour. Our study provides profound arguments from a project perspective which need further elaboration:

First, we recognised reflection on a—completed—TDR project to be an inspiring exercise. The discursive and explorative approach was highly appreciated by the participating scientists and practitioners. Post-project reflection among the case-study partners and feedback

from external TD experts are rare in a research field such as TDR that is often characterised by project orientation and third-party funding. The heuristic, which supports the identification and categorisation of effects (Section 1.2) and the methods applied for ex-post reflection on TDR procedures (Section 2 and Appendix A in Supplementary materials), were perceived as being very useful by the participants of the project fora. This stimulates the search for more opportunities for joint reflection and critical assessment of TDR and its societal (and scientific) effects. We would like to encourage, for example, funding bodies to include this type of moderated reflective process when designing sustainability research programmes (e.g. in the concomitant research projects). Furthermore, the TransImpact team would be very interested to follow up on whether adaptive shaping of TDR processes results in enhanced potential for societal effectiveness of future TDR projects.

Second, our analysis pointed out that the identification, observation and understanding of interests across actors from science and society is crucial in TDR practice—but we hardly found any productive hints for balancing conflicting interests in our sample. Power relations and their relevance for problem definition and team building or during knowledge-generation phases and in the phase of dissemination is a topic worth further investigation in order to avoid naïve treatment of this issue

Third, it seems worthwhile to "translate" the results obtained so far for the benefit of research funders. On the one hand, the results can inform funders how to support TDR projects to generate potential for societal effectiveness. For example, funding conditions should recognise the efforts required for reflexive and adaptive approaches (time and financial resources) as well as enable the development of context-specific and problem-specific clusters that exceed a 'traditional' 3- to 5-year project in TDR. On the other hand, this reformulation for funders' perspective is necessary, since the results presented here are not meant to support evaluations. The shaping processes indicate main areas that have to be reformulated for the evaluation of proposals, project reports or research programmes. So far, it has been difficult to make clear statements about analysing effectiveness ex-post, since this area of evaluation is still in its infancy and not yet mainstreamed. Besides developing criteria, indicators and assessment procedures, emphasis should be placed on concomitant research that both supports effectiveness across projects within a research funding programme via networking, synthesis and transdisciplinary dialogues, and subsequently analyses types of effects during TDR processes.

Fourth, concomitant research or other forms of 'TD meta research' could also deepen understanding of TDR in terms of its results and effects. Since we have so far focussed on societal effects, strengthening the scientific effectiveness in TDR should also be investigated further (see also Newig et al., 2019/in this issue). Additionally, our findings indicate a strong link between the quality of TDR processes and their results but a somewhat opaque link to their effects. The reformulation of these various links into quality criteria is a matter for further debate among researchers, societal actors, and funders, who emphasise different kinds of quality and thus—often implicitly—apply different benchmarks when assessing quality.

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Appendix A. Supplementary data

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