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Transdisciplinarity: Synthesis towards a modular approach

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ABSTRACT

The need to cope with future challenges posed by major transformations such as digitalization and sustainable development has led to several approaches to establish new concepts and methods of science and research. Scientific studies are supposed to provide background knowledge, to facilitate the desired transformations towards a sustainable future and to help resolving complex problems that accompany societies in transition. Concepts such as transformative, transdisciplinary or co-creative approaches elucidate the direction in which scientific research strives for its new role(s). Based on the discussion of these concepts and their different roots, the article proposes a modular concept for a transdisciplinary scientific approach combining and integrating curiosity driven research with goal oriented (advocacy) knowledge generation and catalytic, process-oriented expertise. This integration promises to address some of the deficits of the existing concepts and is particularly suitable for future studies comprising orientation, strategies and reflection for designing policies for transformations.

1. Introduction

Transdisciplinary research has become a key word in the scientific debate on sustainability and social transformation[1] . Exploring cause-effect relationships, developing strategic options for policy and articulating or preparing recommendations for the relevant policymakers from a scientific perspective is not sufficient in the light of a transdisciplinary understanding of research practice (Nowotny, Scott, & Gibbons, 2001, 2017, Lawrence, 2010; Nowotny, 2003; Polk, 2014). On the one hand, there is no scientific consensus on many factual issues. This implies that researcher and practioners need to develop a common understanding of the underlying problems and to co-create options for action in a joint problem exploration and resolution activity (Pohl, 2011). Social learning is key to creating such a common frame for identifying the problem. It implies collective engagement and interaction with others, fosters co-creation of knowledge and means, which is required to transform a situation and to initiate concerted action (Collins & Ison, 2009). The goal is to develop, in the context of a deliberative joint discourse, a solution space from which concrete actions can be prepared.

On the other hand, there are factual topics on which – as in the climate change issue – scientific consensus has existed for decades, but on which the nexus between knowledge, beliefs and action is not functioning because of the complexity of the factual information and its range of interpretations (Mattor et al., 2014; Nanz, Renn, & Lawrence, 2017). It requires a mode of integration that is aimed at establishing a novel, hitherto non-existent connection between the distinct epistemic, social–organizational, and communicative entities that create socially robust orientations (Jahn, Bergmann, & Keil, 2012; Scholz & Steiner, 2015: 529; Thompson Klein, 2010). In

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[1] A summary of this paper focusing on the three basic concepts of sciences has been adopted for the edited volume: Nima Rezaei (ed.): *Integrated Science. Science without Borders.* Springer: New York, to be published in 2021

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view of this situation, transdisciplinary approaches require the establishment of effective links between plural truth claims, diverse societal goals and objectives and the choice of concrete policies. The goal is to integrate the tangled plurality of styles of scientific reasoning or "schemas of intelligibility'' (Berthelot, 1990) that are constitutive of epistemological pluralism (Darbellay, 2015: 171) and develop robust orientations for developing policies that promise to create policy options for coping with possible futures and the contingent interdependence between natural and social context variables, human actions, and random events.

If one accepts that bridging the gap between different pools of knowledge, social orientations and collective action is one of the main objectives of transdisciplinary research, Thomas Jahn et al. have proposed the following properties that, in their view, characterize transdisciplinarity: "Transdisciplinarity is a critical and self-reflexive research approach that relates societal with scientific problems; it produces new knowledge by integrating different scientific and extra-scientific insights; its aim is to contribute to both societal and scientific progress…" (Jahn et al., 2012: 9). More specifically, Renn (2019a) attributes three major properties to the concept of transdisciplinarity:

- Firstly, it addresses research practices that, in addition to the scope of the disciplines involved, transgresses disciplinary approaches by adopting new methods and research designs that are better suited to create a common understanding of complex situations and issues and to develop practical solutions to resolve these issues based on instrumental, scientific, ethical and aesthetic knowledge (Despres, Brais, & Avellan, 2004; Mittelstraß, 1992, 2018: 477; Thompson Klein, 2015: 11).
- Secondly, transdisciplinary research relies on an intensive exchange between diverse knowledge producers and knowledge recipients across all phases of the research process (Krohn, Grunwald, & Ukowitz, 2017; Nowotny, 2000; Scholz & Steiner, 2015). Those who want to use scientific knowledge for political decisions and to apply it concretely need to know not only the results of the research, but also the context conditions and the degree of validity (Kläy, Zimmermann, & Schneider, 2015) Without this expanded concept of knowledge, a proper interpretation of the results is not possible. Moreover, the users and the producers of knowledge are engaged in a mutual dialogue in which both sides add knowledge as well as experience to the learning process of developing a common understanding of the problems and a solution space for policy options (Lang et al., 2012; Pearce & Ejderyan, 2019: 684).
- Thirdly, the transdisciplinary approach is characterized by the deliberate integration of knowledge carriers outside of science involving other actors in problem definition, knowledge generation and problem solution thereby increasing 'legitimacy, ownership and accountability for the problem'. (Hirsch Hadorn, Bradley, Pohl, Rist, & Wiesmann, 2006; Jahn et al., 2012; Schauppenlehner-Kloyber & Penker, 2014).[2] For addressing complex questions, experiential and contextual knowledge of the actors dealing with this question in society are relevant in order to develop not only theoretically conclusive but also practical solutions (Pohl, 2008).

How such transdisciplinary communication processes between knowledge bearers and knowledge recipients can and should be organized in concrete terms is contested in the literature (Brandt et al., 2013; Krohn et al., 2017; Ramadier, 2004; Weingart, 2000). Essential characteristics of such a process are (i) the early involvement of all relevant knowledge carriers, (ii) a learning discourse with the users of knowledge in parallel with each research phase (from agenda setting to interpretation), and (iii) the use of innovative communicative procedures that enable an intensive exchange of arguments, observations, and experiences (Darbellay, 2015: 166; Lang et al., 2012; Patterson et al., 2015: 21ff). The transdisciplinary approach goes, however, beyond the participation of stakeholders in each phase of the research process (Defila & Di Giulio, 2015: 125). Transdisciplinary research is aimed at a jointly supported, integration-oriented merging of different forms of knowledge that are needed for the analysis of a situation and/or for problem solving (Lang et al., 2012; López-Huertas, 2013). Furthermore, transdisciplinary methods are designed to include multiple visions of the future and to include the expectations of the societal actors involved in the research with respect to new evolving trends and transformations. Several authors have emphasized the close connection between transdisciplinary and transformative research (Herrero, Dedeurwaerdere, & Osinski, 2019; Pennington, Simpson, McConnel, Fair, & Baker, 2013). The key to transformation is to create a discourse structure for mutual learning that provides the foundation for addressing wicked problems with long-term implications.

In the literature on transdisciplinary research, there is (so far) hardly any agreement or consent on how to integrate the various approaches, methods, and procedures into a single theoretically convincing and practically feasible concept of transdisciplinarity. Although many authors claim that transdisciplinarity is directed towards unity or at least coherence, there is, after more than three decades of transdisciplinary research, still a confusing multitude of competing concepts and approaches towards transdisciplinarity (Bammer, 2013; Bernstein, 2015; Baveye, Palfreyman, & Otten, 2014; Knapp, Reid, Fernández-Giménez, Klein, & Galvin, 2019; Lyall, Meagher, & Bruce, 2015; von Wehrden et al., 2019) It is not enough to gather stakeholders around a round table and hope that added value would result from the mere fact of having a joint discussion. What is needed is a structured and above all reflected process that is based on profound knowledge of the conditions that govern transdisciplinary discourses. Such process knowledge needs to be theoretically sound, empirically tested, and methodologically reproducible.

This paper is an attempt to develop a conceptual framework that attempts to combine the rigor of (transdisciplinary) *science* with the transformative effect of *transgressive* co-*production of knowledge and orientation.* The need for robust and valid scientific insights is crucial for dealing with complex issues since intuition and common sense are likely to fail in these circumstances. At the same time,

[2] Jaeger and Scheringer (2018) consider this third aspect of including non-scientific knowledge carriers to be not constitutive for the understanding of transdisciplinary research. In my view, however, this necessity arises from the function of a problem-oriented and interdisciplinary approach. Non-scientific knowledge (such as experiential knowledge) can make an essential contribution to understanding a problem and, above all, to solving problems.

producing valid descriptions of complex structures is insufficient for developing and implementing evidence-informed policy options (SAPEA. Science Advise for Policy by European Academies, 2019: 26). How to combine these two aspects of transdisciplinarity will be the main focus of this paper. First, I will give a brief review of the various schools and concepts that in my view have structured the discourse on transdisciplinarity.[3] I will show that neither one of the reviewed concepts, as valuable as they may be, will provide a clear concept of how to integrate scientific excellency, future orientation, practical relevance and social coherence. Based on this analysis, I will propose a new modular approach for integrating transdisciplinary scientific knowledge into societal transformation discourses and democratic policymaking.

2. Traditions and concepts of transdisciplinarity

2.1. Overview

The concept of transdisciplinarity emerged in the 1970s to the 1990s as a new approach for addressing complex and controversial issues. Transdisciplinary approaches gained ground in connection with efforts to cope with *wicked problems* (Rittel & Webber, 1973: introduced to the transdisciplinary research concept by Brown et al., 2010 and 2015), the debate on post-normal science (Funtowicz & Ravetz, 1993), and the division of scientific approaches into Mode 1 and Mode 2 research (Gibbons et al., 1994; Nowotny, Scott, & Gibbons, 2003). These approaches differed from the more established concepts of multi- and interdisciplinary research in the way that they transcend disciplinary boundaries and create a major reconfiguration of disciplinary divisions within a systemic, global and integrated perspective (Darbellay, 2015: 166). They address socially contested challenges and include the idea of extended peer review, in particular between different disciplines. Furthermore, actors from outside the scientific field contribute to the construction of knowledge and co-create, together with scientists, practical solutions of social problems (Lawrence & Després, 2004: 403). This transdisciplinary involvement of practitioners was seen as a prerequisite for dealing with problems characterized by complex causal structures and interconnections, uncertainties around the relationship(s) between causes and effects, and challenging ambiguities (Polk, 2014; Scholz & Steiner, 2015). In particular, transdisciplinary approaches were expected to prove their worth in addressing the tensions between the contextuality and universality of scientific knowledge (Balsiger, 2004; Nowotny et al., 2001; Thompson Klein, 2010, 2015; López-Huertas, 2013). Transdisciplinary concepts were particularly promoted by scholars from the new field of sustainability sciences, but were also advocated and applied in other areas such as community development, public health, urban and land-use planning and digitalization.

Over time, a number of different perspectives and concepts relating to the theoretical foundations and practical implementation of transdisciplinary approaches emerged worldwide. The progress in transdisciplinary research has been documented in two special issues of Futures in 2004 (vol. 36) and 2015 (vol. 65). In the beginning of the debate, two major concepts evolved: the transgressive school of Nicolescu (2002, 2012) and the so-called Swiss (polycentric) school mainly represented by European authors who laid down the foundations of their understanding in a seminal conference in Zuerich, Switzerland (Thompson Klein, 2008, Thompson Klein, 2015; McGregor, 2015; Scholz & Steiner, 2015). This crude dualism has given rise to a multitude of competing and complementing concepts that all relate to the theoretical roots of addressing complex real-world problems by means of knowledge integration and common good orientation. It is not possible to cover all of these approaches in detail here (see systematic reviews in Bernstein, 2015; Despres et al., 2004; Lang et al., 2012; Max-Neef, 2005; McGregor, 2017; Thompson Klein, 2010, 2015; Von Wehrden, Guimarães, & Bina, 2019). However, to provide a better understanding for my own proposal of integrating three major components of research concepts to constitute a modular approach to transdisciplinarity, I will present a brief outline of five concepts (mainly related to sustainability transformations) that are particularly relevant for my argumentation. These five concepts relate specifically to the question of how scientific methodology and rigor can be aligned with stakeholder perceptions, values and interest in a world of plural cognitive, ethical and aesthetical claims.

- The Anglo-Saxon concept of a new inner-scientific orientation towards the treatment of complex and socially controversial questions, especially with regard to sustainability science, which emerged in response to the conditions that initially prompted the development of transdisciplinary approaches (most prominently, Jantsch, 1972; with respect to sustainability: Frodeman, 2014; Grin, Rotmans, & Schot, 2010; Leavy, 2011; Kates et al., 2001; Miller et al., 2008)
- The approach proposed by Jürgen Mittelstraß, Martin Scheringer, Jochen Jaeger and others, which focusses on real-world problems and the associated changes in the scientific system and research practice, including a transgression from disciplinary analytical thinking to an out-of-the-box, transcending synthesis of scientific principles and methods (most prominently Mittelstrass, 2011).
- The concept put forward by the German socio-ecological tradition, which focusses on integrating rigid scientific methods and practice in collaboration with and inclusion of affected people and groups (most prominently, Bergmann et al., 2005, 2012; Lang et al., 2012).
- The concept of epistemic integration envisioning transdisciplinarity as a mutual learning process in which scientists and practitioners integrate systematic knowledge and experience as equally valid forms of knowledge (most prominently, Scholz, 2000; Scholz & Steiner, 2015).

[3] It should be noted that this paper does not include a systematic review based on a formal search methodology but is rather based on a synthesis of the literature referring to proposals and concepts describing the nexus between science and practice, in particular to transformative science for sustainable development.

- The concept of common good orientation viewing transdisciplinarity as a form of discourse between scientists and practitioners that is oriented towards negotiating societal improvements of public welfare (most prominently, Hirsch Hadorn et al., 2006 and Hirsch Hadorn et al., 2008).

In addition to this, I will describe several attempts of scholars to synthesize these different concepts. At the end of this section, I will highlight the problems and pitfalls that are associated with these concepts of transdisciplinarity.

2.2. Concept 1: Transdisciplinarity as solution to wicked problems

An early concept forged in the context of post-normal science (Gibbons & Nowotny, 2001; Gibbons et al., 1994; Nowotny et al., 2001, 2003) proposed inter- and transdisciplinary approaches in response to the question of how science can adequately address complex problems and issues mired in controversy and address socially contested and scientifically uncertain issues (Funtowicz & Ravetz, 1993; Thompson Klein, 2015: 11). In view of the challenges of breaking complex phenomena down into their causal components, dealing with uncertainties in the identification of causal and functional relationships, and addressing ambiguities in the interpretation of both the initial situation and possible solutions, the proponents of this approach to transdisciplinarity advise researchers to systematically collect and characterize knowledge from different scientific sources and disciplines, add contextual knowledge that is needed to properly understand a problem, to apply this knowledge to a specific situation, and, as far as is necessary, draw on other knowledge sources that are relevant to the task of understanding or addressing the problem (Gibbons & Nowotny, 2001).

When a problem is characterized by a high degree of complexity and uncertainty, the proponents of this concept suggest that “socially robust” knowledge must be created by integrating perspectives that have not yet been considered (Nowotny, 1999, 2000). In addition, this concept explicitly includes the perspective of future generations who will benefit or suffer from decisions made today. Funtowicz and Ravetz (1993) pointed to ecological economics as an example of a field that stems from this tradition. It is the transdisciplinary imagination, a synthesis of interdisciplinary knowledge, normative orientations and artistic expressions of aesthetics, that provides a more holistic answer towards addressing such problems (Brown et al., 2010; Despres et al., 2004: 477; Robinson, 2008). But an orientation on uncertain knowledge is also central to more recent approaches, including the concept of real-world experiments introduced by Matthias Groß and others. In their view, “a real-world experiment can structure how we deal with uncertainty and ignorance” (Groß, Hoffmann-Riem, & Krohn, 2005: 210; Schneidewind et al., 2018). In this understanding, transdisciplinary approaches serve as a kind of research heuristics that makes social orientation and collective action possible despite uncertainty, disagreement, and complexity. Another variant of this understanding promotes transdisciplinary *action* research as a means of involving researchers directly into actions that promote the transformation towards sustainability (Bradbury & Reason, 2003; Wiek, Ness, Schweizer-Ries, Band, & Farioli, 2012; Witmayer & Schäpke, 2014).

2.3. Concept 2: Transdisciplinarity as a unifying approach to problem-oriented, transcending research

The involvement of non-scientific actors is not constitutive for the approach advocated by Juergen Mittelstraß and others (Jaeger & Scheringer, 1998, 2018; Mittelstrass, 2011). Here, the focus is rather on the differentiation between theoretical and practical perspectives when applying transdisciplinarity into the real world. For transdisciplinary research, theoretical and practical knowledge must be collected and evaluated in a systematic process of knowledge organization. Practical applications of transdisciplinarity take their cue from real-world problems and seek out the knowledge, interests and values that are essential to solving these problems. Ideally, theoretical and practical approaches are combined in transdisciplinary projects. Non-scientific actors play a role only to the extent that they provide important perspectives and standards for the selection and evaluation of knowledge. This approach focusses on organization within the scientific domains (based on preliminary thoughts by Jantsch, 1972). Cooperation in the area of transdisciplinary research is expected to lead to a permanent reordering of the scientific system that will change the outlooks of individual subjects and disciplines. Transdisciplinary research can thus be seen as a reform program for academia (Mittelstraß, 2018). This understanding of transdisciplinarity has also influenced the field of education as an opportunity for a new learning space that is problem-oriented, focused on integration of knowledge and design, directed towards common purposes (for example sustainable development) and leading towards practical actions or behavioral intentions (Brown & Lambert, 2012; Neuhauser & Pohl, 2014; Kochhar-Lindgren & Kochhar-Lindgren, 2018; Pohl, Pearce, Mader, Senn, & Krütli, 2020).

2.4. Concept 3: Transdisciplinarity as bridge between science and action

The difference between theoretical and practical approaches lies at the heart of the nuanced conceptualization of transdisciplinary approaches developed by a team of scholars devoted so a *socio-ecological systems* perspective (Bergmann et al., 2005, 2012; Lang et al., 2012). The proponents of this concept distinguish between a science-focused, a real-world focused, and an integrative approach to transdisciplinary research and advocate integrative transdisciplinarity as a means to bridge science and real word. In addition to classical features of interdisciplinary cooperation, the linking of research to relevant contexts and a focus on complex and socially controversial problems, this approach promotes a deliberative methodology to combine scientific knowledge with the experience and contextual knowledge of affected groups and people (Jahn et al., 2012). This is illustrated in the diagram below, where the two central contexts of transdisciplinary work – science and the real world – are connected in a process of transdisciplinary integration.

Transdisciplinary research is characterized by four types of knowledge integration, which are summarized in Table1:

Transdisciplinary research, the authors argue, is about connecting system knowledge (What do we know about the problem and its context?) and orientation/target knowledge (Where do we want to go? Which values do we want to uphold?) with transformation knowledge (How do we achieve a desired outcome?) Each of these three forms of knowledge calls for different combinations of systemic insights from the sciences (from both a disciplinary and interdisciplinary perspective) and the experiential or contextual knowledge of the affected individuals and groups (Rosendahl, Zanella, Rist, & Weigelt, 2015: 18). The authors have developed a variety of methodological procedures and phase models to ensure scientific rigor while also integrating other practice-oriented bodies of knowledge.

2.5. *Concept 4: Transdisciplinarity as a merger of scientific and practical knowledge*

Integration of knowledge and practice also takes center stage in a concept that has been shaped substantially by the work of Roland Scholz and others (Scholz & Stauffacher, 2009; Scholz & Steiner, 2015; Scholz, 2000; Scholz, Lang, Wiek, Walter, & Stauffacher, 2006; Scholz, 2017; Scholz, Czichos, Parycek, & Lampoltshammer, 2020). For Scholz and colleagues, dialogue must occur on an equal footing in a mutual learning process involving scientists and practitioners. Scientific knowledge and practical/experiential knowledge are considered to be complementary and cannot be played off against each other. Both forms of knowledge are essential to arriving at a common understanding of the problem and developing solutions that are both scientifically valid and realizable. The main features and principles of this approach are detailed in Table 2 below.

2.6. *Concept 5: Orientation towards the common good*

A variation on concept 4 has been developed by Gertrude Hirsch Hadorn, Christian Pohl and others (Hirsch Hadorn et al., 2006; Pohl, 2010; Pohl & Hirsch Hadorn et al., 2008). In the beginning, the authors have adopted the phase model developed by Jahn et al. (see Fig. 1) and emphasized, in accordance with Scholz, the importance of mutual learning, but introduced a normative orientation towards the common good as the guiding principle for the integration of scientific and non-scientific knowledge. According to Pohl and Hirsch Hadorn (2007), this is the only way that the conflicting truth claims by different actors can be resolved in an ethically justified manner. Knowledge integration can only succeed if it is guided by two principles: (a) what is scientifically robust when relying on causal assumptions and (b) what is normatively serving public welfare when making choices about options. These principles are further delineated in Table 3.

2.7. *Synthesis of concepts*

Many authors have tried to develop a list of properties that characterize the common principles of all transdisciplinary approaches. Formal and systematic meta-analytical publications outside of specific domains (see for example: Darbellay, 2015) are not yet available to my knowledge but several comprehensive literature reviews and synopses have been published over the last two decades. Most pronounced are the two special issues of Futures that were devoted to transdisciplinary approaches in 2004 and 2015. In addition to these two volumes, there have been several articles that have produced a list of common principles that are proposed to govern transdisciplinary research. The following paragraphs summarize several of these reviews that are specifically related to the relationship between scientific inquiry, inclusion of non-scientific actors, and practical applications.

In several reviews of transdisciplinary approaches, Julie Thompson Klein (2008; 2010; 2015: 11) suggests that the three main characteristics of transdisciplinarity are: (i) *Transcendence* (overcoming disciplinary boundaries and developing one's own transdisciplinary perspective and, if necessary, methodology); (ii) *problem orientation and solving* (problem recognition and developing of solution spaces with the support of relevant knowledge and competences); and (iii) *transgression* (the deliberate inclusion of idiosyncratic, contextual features and their interaction(s) with cross-case transferable or scalable experiences). These three fairly abstract attributes have been echoed by many other reviewers in the field (i.e. Bernstein, 2015; Gibbs & Beavis, 2020; Leavy, 2011).

Another, more pragmatic approach to come up with a synopsis of transdisciplinary approaches has been developed by Dubielzig and Schaltegger (2004). The two authors reviewed more than 120 conceptual papers and came up with five major components that, in their view, are common to almost all concepts:

- Pressing problems affecting everyone's life (Lebenswelt) as a starting point;
- cross-disciplinary competence;
- inclusion of new methods, structures and practical applications in the research process (integrative creation of methods and knowledge);

Table 1
Four main types of integration.

Symmetric integration (balance between the generation of knowledge for the purpose of guiding action and for the purpose of gaining insights)
Integration of the social and natural sciences (the integration of knowledge relating to the natural world and society),
Integration of formal and empirical research (connecting formal scientific outputs such as models and simulations with case studies and other, context-specific approaches) and
Theoretical and conceptual integration (the creation of a common conceptual framework that is acceptable to both scientific actors and partners from the field).

Adopted from Bergmann et al. (2012: 42-45).

Table 2
Essential features of transdisciplinary dialogues according to Scholz et al. (2020: 642).

Features and principles of a genuinely transdisciplinary research process
A number of special features distinguish transdisciplinary research processes from other forms of science-practice collaboration. These include:

- **Co-leadership by scientists and practitioners** at all levels of the project
- **Science sees its role as serving the public good**; this contrasts with other conceptions such as that of the "science activist"
- **Recognition of the otherness of the other**, of his/her role, values, way of thinking, etc.
- **Differentiation of roles** and consideration of perspectives and interests both between and within science and practice
- **Recognition that scientific knowledge and practical knowledge are equally valid**
- **Joint generation and continuous revision of orientation knowledge**
- **Joint definition, representation and transformation** of the identified problem
- **Mutual learning** as the basic principle of the transdisciplinary discourse
- **Method-based integration of knowledge and theory-practice collaboration**
- **Creating a protected discourse arena** in which preliminary thoughts can be formulated, discussed and developed
- **Deliberative, evidence-based, scientific analysis** for poorly understood problems
- **Acknowledgement of the limitations of knowledge**, i.e., the uncertainties, blind spots, context dependency, etc. of statements
- **(Socially robust) guidance** instead of (long lists of) **recommendations**
- **Sponsoring** instead of contract-based research
- **Facilitation** of the discourse between scientists and practitioners

- competence in the underlying disciplines (good science);
- straight integration of research, practice, transfer and teaching ;
- integration of different knowledge stocks and mutual learning of theory and practice.

These points address many issues that other scholars have been using for characterizing transdisciplinary approaches (cf. Darbellay, 2015: 166; Despres et al., 2004: 475; Jahn et al., 2012: 8; Lawrence, 2010, 2017; Pohl, 2011; Serrao-Neumann et al., 2015: 16; Von Wehrden et al., 2019: 876). In a recent review article in GAIA, Krohn et al. (2017) attempted to summarize the discussion on transdisciplinary approaches. In their conclusion, they identify the following four important characteristics of transdisciplinary research approaches:

- A multidisciplinary perspective on problems and situations that cannot be addressed using conventional analytical methods;
- a focus on transformation towards sustainability as an underlying normative orientation;
- a form of abstracting from context-specific problems by analogy; and
- the involvement of non-scientific actors in the process of generating knowledge and guidance for action.

Other reviews have focused on the phases of transdisciplinary research practices. Beyond the already cited work of Bergmann et al. (2012), the phase model of Defila and Di Giulio (2015) with its emphasis on interim phases of knowledge integration and the model of Godemann and Michelsen (2008: 196-197) with an emphasis of co-creating a common knowledge base and joint mental models should be mentioned here.

2.8. Shortcomings of transdisciplinary concepts

There is an abundance of proposals for characterizing the basic principles of transdisciplinary approaches and a wealth of guidance documents for methods and procedures that provide orientations for informing transdisciplinary research (i.e. the two-volume methodology handbook by Defila & Di Giulio from 2018/2019). However, in my view, there are still several shortcomings and problems associated with the concept of transdisciplinarity that demand more attention and refinement. The relationship between transdisciplinary, interdisciplinary and disciplinary concepts remain vague and often confusing (Maasen & Lieven, 2006). What is the role of classic science approaches in transdisciplinary research? How are conflicts been handled when scientific truth claims contrast with the experiential knowledge of stakeholders? Brand et al. diagnosed in many transdisciplinary studies a lack of coherent research framing, a difficulty in integrating distinct research methods towards a coherent approach, a need for rigorous methods for evaluating the research design, a convincing concept for measuring quality and applicability of produced knowledge and a clear scientific interpretation for the role and function of meaningful engagement of stakeholders for knowledge production (Brandt et al., 2013). The main body of transdisciplinary literature recommends a better reliance on robust knowledge, excellent science and evidence-informed judgements (Burger & Kamber, 2003; Pohl, 2008). This concern is echoed by Popa, Guillermin, and Dedeurwaerdere, 2015: 47):

> "Without an explicit reflexive dimension, transdisciplinarity is confronted with the risk of either being reduced to formal social consultation, with no real impact in how knowledge is generated or integrated into policy-making, or evolving towards a politicized form of 'democratic science' in which epistemic aspects are subordinated to procedures of social legitimation. In such a situation, the explanatory shortcomings, lack of clear normative orientation and perceived 'hidden agendas' of research can severely undermine public trust and the legitimacy of scientific knowledge, weakening its capacity to inform and guide policymaking."

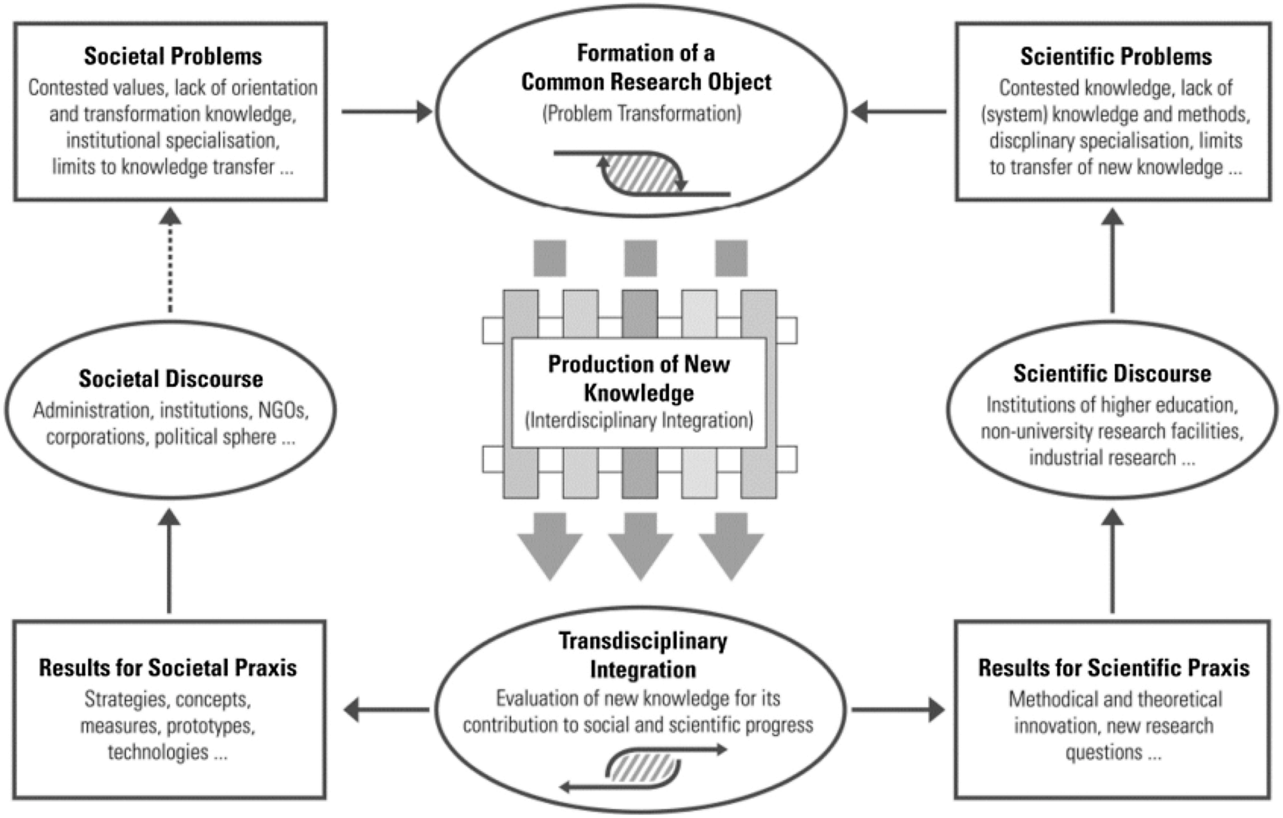

Fig. 1. The integration of societal and scientific praxis in transdisciplinary research.
Source: Jahn et al. (2012: 8).

Table 3
Principles of transdisciplinary research (Pohl & Hirsch Hadorn, 2007: 16-19 and 23).

Understanding the complexity of the problem (complexity can be reduced by focusing on those knowledge elements that all actors need in order to understand the situation and guide their own actions)
Emphasizing the diversity of perspectives on a problem (providing pluralism and contextualization)
Linking abstract knowledge, case-specific knowledge and practical knowledge (accomplish integration of different types of knowledge through discourse)
Developing robust orientations towards the common good (based on a thorough reflection of conflicting goals and the assignment of trade-offs between options and their impacts)

The epistemic question of how to resolve conflicting truth claims between science, practical application and stakeholder interests remains unresolved in spite of many efforts to introduce reflexivity as a potentially integrating force (Balsiger, 2004; Böschen, 2019; Brandt et al., 2013; Jahn et al., 2012; Rosendahl et al., 2015; Truffer, 2007).

The tension between curiosity driven research and advocacy for a special cause (as noble as it may be) is also frequently mentioned in the literature (i.e. Maasen & Dickel, 2019; Russell, Wickson, & Carew, 2008; Weingart, 2000: Wickson, Carew, & Russell, 2006). Suggesting joint fact-finding methods and engaging in a deliberative discourse may produce *procedural* forms of resolving this tension. However, it remains unclear how these tensions can be addressed *substantively* (Defila & Di Giulio, 2015; Rosendahl et al., 2015). In a very critical review, the former president of the German Science Foundation, Peter Strohschneider (2014) criticized transdisciplinary research as being torn between the need for rigorous scientific methods combined with an impartial search for causal explanation and the normative orientation of promoting sustainability or other political objectives[4] . Such a tension, so his analysis, could lead to wishful thinking, partialized truth claims, and in the end to a delegitimization of science as an impartial broker (Miller et al., 2014; Pielke, 2007).

Similarly, several authors have highlighted the potential conflicts between epistemic and democratic ideals (Hendriks, 2009; Polk, 2014; Popa et al., 2015; Robinson, 2008). Maasen, Lengwiler, and Guggenheim (2006) have emphasized the unresolvable tension that arises between normative and epistemological demands when scientific research is expected to be both reliable and justifiable. In the course of transdisciplinary research, they believe that normative constraints move from the periphery to the epistemic core of science, encouraging a shift in the role of scientists from analysis to intervention. The criticism of Maasen and her colleagues centers on the question of how to deal in a responsible way with the fact that participation in science is generally discussed in the context of the normative goal of democratizing science with the ultimate aim of expanding the democratization process itself. This may, however, contrast with the other immanent goal to enhance our knowledge about the causal and functional relationships in the natural and social world. Maasen and Dickel (2019) also point out to the potential conflicts of including non-epistemological values into scientific research such as sustainability, ethical acceptability, and productivity. The clash of different rationalities between scientific and political thinking cannot be overcome by initiating a common discourse among all parties and hope for the integrative power of reflexivity as a panacea for resolving conflicts (Rosendahl et al., 2015; Rydin, 2007; Watson, 2003). Truth claims, values, interests and preferences are all intertwined but they cannot be integrated into a single unity. The best one can hope for is coherence among and between these discourse components (Brandt et al., 2013; Lawrence & Després, 2004; Ramadier, 2004: 429). There is a need for developing a framework in which a multitude of rationalities can coexist without being coerced to merge and still become coherent and constructive forces in their quest for the common good.

In my view, these critical issues have not been adequately addressed in the literature on transdisciplinarity so far. In particular, the question of how (i) classic, curiosity driven science (disciplinary and interdisciplinary), (ii) goal-oriented, often advocacy science and (iii) the inclusion of knowledge by non-scientific actors can be integrated into a coherent framework remains an unresolved topic in the conceptual literature but also in the practical guidelines for designing a transdisciplinary discourse that promises to produce scientifically valid and politically relevant orientations based on best available evidence, inclusion of major stakeholders' perspectives and in compliance with democratic principles. There are many case studies and empirical accounts for addressing this quest for a coherent transdisciplinary approach (for example: Bergmann et al., 2005; Paterson, Isaacs, Hara, Jarre, & Moloney, 2010; Scholz et al., 2006; Serrao-Neumann et al., 2015; Zscheichler and Rogga, 2015). However, these studies do not offer a conceptual framework but represent pragmatic solutions to a given problem within a specific application context. The following paragraphs are an attempt to address this gap and develop a modular approach of transdisciplinarity as a combination of curiosity-driven, goal-oriented and catalytic research traditions[5] .

[4] The very critical review by Strohmeier triggered a major debate and several proponents of the transdisciplinary research communities replied to the accusations (i.e. Grunwald, 2015; Schneidewind, 2015).

[5] The following outline for a new concept of transdisciplinarity has not been published in English. However, there are two German articles that contain similar ideas (Renn, 2019a and 2019b). Beyond the classic model of disciplinary and interdisciplinary scientific research, a distinction is often made between transformation research and transformative research (Grunwald, 2015; Kläy et al., 2015). In the terminology presented here, transformation research is most likely to be assigned to the curiosity-driven concept of science (general and systematic insights into transformation processes) and transformative research to the goal-oriented concept (supporting transformative goal attainment). The novel aspect here is the catalytic component: Research should facilitate processes that promote policies and actions in a multi-value and multi-actor society based on both, best available evidence and common good orientation, including methods of addressing, reflecting and resolving trade-offs.

3. Transdisciplinarity: towards a modular but coherent framework based on three research traditions

3.1. The curiosity driven research concept

In order to locate the appropriate function of science and research for transdisciplinary research in the context of current transformations, it seems important to me to differentiate between three basic concepts of scientific research traditions and the types of knowledge associated with each of them.

The first concept comprises the classical understanding of curiosity-driven research (classic science) (Greenberg, 1968; Van Fraassen, 1995; Zimann, 2000; in line with my argument: Bast, 2020). Jon Agar has characterized the evolution towards curiosity-driven research by referring to a development from 'basic science' to 'mission-oriented science' and further to 'curiosity--driven research' This evolution "has provided important tools used to create and manage the apparent social autonomy that is functional in sustaining science. The social contract has been that science will deliver, if left autonomous" (Agar, 2016).

The aim of scientific activities in this scientific tradition is to find valid insights into as yet unknown connections between phenomena or dynamic developments. The driving force behind these activities is curiosity; the aim is to uncover causal or functional relationships without any specific goal of application or implementation in mind. The research is directed towards using proven methods of gaining additional insights and integrating these new discoveries into a consistent body of existing knowledge. All parties in society thus receive the necessary background knowledge to inform themselves on factual issues and to become familiar with the state-of-the art in regard to systematic knowledge. This enlightenment function of science without consideration of interests, social preferences and political contexts is not a sign of ivory-tower thinking, as so often caricatured, but a necessary and indispensable corrective against wishful thinking and ideological blinkers (Calvert, 2006; Weiss, 1977). Science is never unconditional, it is based on normative assumptions and conventions, but it can produce findings in the space beyond interests, which helps to prevent unpleasant surprises for all those involved (Miller et al., 2014; SAPEA. Science Advise for Policy by European Academies, 2019: 58).

The results of curiosity-driven research therefore provide insights into causal or functional processes. Such knowledge is relevant for implementation in politics and business (in particular if Mode 1 issues are addressed). If a research team found out, for example, which incentives could lead to greater energy efficiency or energy savings among consumers, policy makers could consciously introduce these incentives as policy options in order to better achieve the goal of energy system transformation.

Curiosity-driven research is typical for many disciplines such as chemistry, physics or history and rests upon established methodological rules and techniques. For being a component within a transdisciplinary concept of research, it needs to go beyond single disciplines, since a better understanding of complex and wicked problems (Mode 2) requires more than a disciplinary focus (Brown, 2015; Nowotny, 2000). Rather, an integrative approach is needed that simultaneously illuminates the various aspects of the phenomenon to be investigated and, above all, captures their interactions. The term systems knowledge has become established in the specialist literature for this purpose (Daschkeit, 2006; Jahn et al., 2012; Patterson et al., 2015). This refers to knowledge that describes and analyses the various facets of a phenomenon in their systemic interaction and understands them in their holistic interrelationships (Nanz et al., 2017; Scholz, 2017). Systems knowledge is therefore inevitably interdisciplinary, i.e. it is aimed at uncovering relationship patterns that encompass and integrate the scope of several disciplines (Ramadier, 2004; Thompson Klein, 2013). Yet, the research design may still be curiosity-driven and governed by the traditional quality standards of each scientific discipline involved (Kockelmans, 1979).

There is no doubt that there are a number of problems associated with the classic understanding of science: One major problem is that in the case of complex and stochastic interrelationships, a clearly causal or even functional understanding of the relationships is hard, if not impossible, to accomplish (Spiegelhalter & Riesch, 2011). Moreover, even if knowledge of functional interrelationships is available a direct translation into political action is often impeded by unfavorable context conditions (Sanderson, 2006). Investigators may be able to identify particularly effective incentives for energy-saving behavior through laboratory experiments. When applied to everyday political life, these incentives may not work at all, either because the framework conditions do not match the experimental context or because there are other political or social circumstances that weaken the effect of all the chosen incentives. After all, in a concrete political situation there are always many actors operating at the same time, whose interactions are difficult to grasp by scientific methods (Lang et al., 2012; Van der Sluijs, Petersen, Janssen, Risbey, & Ravetz, 2008).

3.2. The goad-oriented concept

In order to design research agendas to specific situations and contexts, there is a second concept of scientific research, which can best be described by the term "goal-oriented research" (mission-oriented, or –more provocative– advocacy science). Goal-oriented research dissolves the distinction between basic and applied research, which has become obsolete (Gooday, 2012). Rather, it is the acquisition of knowledge oriented towards a specific benefit or problem solution that can be approached systematically with both basic and applied research[6] . Goal-oriented research produces knowledge that policy makers can use as strategies for achieving goals or solving problems. In particular, it links the present with the future: once goals for the future are determined (i.e. climate neutral energy production in the year 2050), the researchers develop strategies and policies that help society to reach its predefined goals. Policy makers or other shapers of social reality (such as business or civil society groups) either set goals for science that are to be achieved by a

[6] In Donald Stokes' well-known four-field scheme of scientific research (Stokes, 1997), this research represents the second dimension of research: benefit orientation. This can be both basic and practical. I follow here the argumentation of Jahn et al. (2012).

certain point in time (e.g. energy system transformation in 2050) or address problems that are to be solved using the best evidence available. In the literature on forms of contemporary policy advice, this function of science is often described as strategic or instrumental (Ingold & Gschwend, 2014). Most of the time, goad oriented knowledge relates to complex, often wicked problems that are ill-defined but where most of the actors agree that they require political interventions in order to avoid negative outcomes or developments in the future (Brown et al., 2010).

Goal orientation comes in two variants: In the first case, social groups set targets. These can be targets for energy system transformation, such as the 100 percent replacement of fossil fuels by renewable energy sources by 2050; in the second case, the research addresses conditions that are regarded as "problematic" by certain groups or by policy making bodies. These problems should be resolved towards a more desirable state, such as more sustainable food production or finding more equitable solutions when distributing income. What is regarded as desirable is defined in advance, ideally in a deliberative orientation discourse. In many cases, a consent of what is regarded as desirable may be based on an implicit consensus in society (more climate protection is better than less) or may have been negotiated in a political discourse involving ethical expertise (for example, more investment in resilience after experiencing a pandemic crisis). In other cases, scientific advice is demanded for partial, interest-based goals or group-specific problem views. This is normally associated with advocacy research (Cristi, Horton, Peterson, Banerjee, & Peterson, 2016). For example, environmental protection groups or business associations can commission expert reports that take up their view of the problems and develop strategies that serve their specific objectives. Irrespective of the client and their interests or concerns, the common feature of goal-oriented research is to provide options or proposed solutions for clients from politics, business and civil society that, to the best of their knowledge, meet specified goals within the specified time frame or help solve specific problems in a way that is appropriate and reflect the values of the respective policy makers. It is obvious that this research tradition is value-based and not driven by curiosity. It also reflects the concept of constructed or manufactured science as it is based on the idea of designing pathways for reaching a specific purpose (Knorr Cetina, 1981; for transdisciplinarity, Ramadier, 2004).

In the literature, this second form is often referred to as orientation or target knowledge (Hirsch Hadorn et al., 2008; Jahn, 2013; ProClim, 1997; Rosendahl et al., 2015). However, this denomination applies only to the normative part of goal-oriented science. In fact, orientation is a necessary step in order to morally justify and (democratically) legitimize the goals to be pursued. Once the goals are agreed upon, the essential task of the research team is to design (alternative) strategies for achieving the goals and to assess their effects and side effects. This requires both analytical and normative expertise: analytical expertise in order to assess the effects and side effects, but also normative judgements in order to resolve or at least constructively address conflicting values and to construct meaningful and defensible trade-offs.

Similar to the curiosity-driven research tradition, goal-oriented research also faces numerous problems and pitfalls. One major problem is that, as the name suggests, the research team is tied into a predetermined corset of objectives (Guston, 2000; Weingart, 2000). It is possible, for example, that there are other objectives that could better implement the original intentions associated with the objectives at a higher level. Perhaps there are also other variants which, with fewer side effects, can achieve the originally intended purposes just as effectively (or even more effectively). In climate protection, for example, one might think of negative emissions or drastic lifestyle changes. After all, goals are not set in stone, and they have to be constantly adapted by means of social discourse and reflected upon again and again.

Moreover, with the goal-oriented variant there is always the danger that in the conflict between the achievement of goals and the results of scientific research, loyalty to the goals carries more weight than loyalty to the methodological rules of finding knowledge in the respective sciences (Nielsen, 2001; Popa et al., 2015). This danger is all the greater the more the topic itself requires an interdisciplinary approach and the more it is already associated with great uncertainties and ambiguities from a scientific perspective. In addition, goal-oriented research is often conducted by scientists who themselves share these goals and may be biased against any evidence that may contradict these goals or may suggest much more effort to reach them in time.

3.3. *The catalytic concept*

The last and third variant of scientific research is less clearly defined and has been labelled as participatory (Mobjörk, 2010; Witmayer & Schäpke, 2014); deliberative (Forester, 1999; Nowotny, 2003) or reflective (Popa et al., 2015; Stirling, 2006). It is aimed at integrating knowledge outside of the scientific communities and provide models for deliberation in which knowledge claims, interests, values and preferences can be included and integrated for designing policy options. In my own writing, I have referred to this concept as the catalytic approach to research (most recently in Renn, 2019a/2019b). Scholz (2017: 23) uses the same term for characterizing the transformative nature of transdisciplinarity: "TSc (Transformation science) follows the vision of the scientist as an initiator of and catalyst for sustainable transitioning". However, beyond its mere mentioning, the catalytic understanding of science has not entered the debate about the concept of transdisciplinarity. In my understanding, the catalytic function of science assumes the task to systematically collect the knowledge from a variety of scientific communities, but also from other sources of knowledge, which may be instrumental for problem solving, to reorganize and restructure the various knowledge elements and to feed them into a deliberative discourse for the purpose of creating a mutual understanding among all participants (Lejano & Stokols, 2013; Renn, 2014; Wittmayer, Avelino, van Steenbergen, & Loorbach, 2016). Similar to chemical catalysis, decision-making processes need to be designed and implemented that facilitate synthesis. These new designs should help all actors in a multi-value and multi-actor society to co-create robust orientations for action that are based on best scientific evidence and informed by plural values and interests. The goal is to resolve trade-offs inspired by a discursive agreement on the common good. Above all, conflicts are to be identified, the underlying knowledge assumptions, but also the values, interests and preferences associated with them are to be disclosed, and joint approaches to solutions are to be developed, which are based on robust knowledge, generally accepted normative principles and fair negotiation of interests. According to this concept, the systematically collected knowledge elements are transferred into a new format that is understandable and comprehensible for all participants, so that a proper discourse appropriate to the plural values can be conducted (Polk, 2015; Renn & Schweizer, 2020; Webler, 1995). In this discourse, the different knowledge carriers meet with the knowledge users and discuss the initial situation, jointly reflect the different views of the problem (frames) and develop evidence-informed and value-based solutions for society (Bremer, 2013; Petts, Owens, & Bulkeley, 2008). The catalytic framework is particularly important for addressing problems with long-term implications. Very often, we lack adequate institutional processes to deal with issues that require investments today for avoiding potential damages in the future (Dittrich, Wreford, & Moran, 2016).

The catalytic understanding of science is more than just a new domain for the social sciences and especially the communication sciences aimed at conflict management and discourse design. It puts science in the role of an "honest broker", a mediator between competing truth claims, options for action and moral justifications of distribution keys for public goods and burdens (impositions) (Pielke, 2007). In the spirit of Jürgen Habermas' Rational Discourse, the catalytic research team explores and implements the structural and procedural conditions that are necessary for a factually sound formation of judgement that also reflects the plurality of values (Chambers, 1996: 90ff; Despres et al., 2004: 477; Habermas, 1984: 44ff). It is a matter of the institutional and organizational conditions that guarantee an effective and fair exchange of arguments (speech acts), in which not the status of the speaker, but the claims to validity associated with each statement are used as a yardstick for collective agreement. The aim is an understanding-oriented approach through which all actors can bring in their claims to validity and jointly redeem them (Bohman, 1996, Rosa, Renn, & McCright, 2014; Webler, 1995: 110ff). In particular, such a discourse includes aesthetic, instrumental, scientific and ethical arguments as legitimate contributions for identifying the problem and constructing a solution space (Despres et al., 2004: 477). This requires not only robust process knowledge based on scientific methods, procedures and testing procedures, but also communicative competencies, prudent judgment capabilities and negotiating skills (Rosa et al., 2014; Webler, 1999: 170ff.). Evidence-informed, effective and fair resolution of trade-offs is crucial for the success of such processes.

This demand is echoed by the *phronetic* social science concept as advocated by Flyvbjerg and colleagues (Flyvbjerg, Landman, & Schram, 2012; Schram, 2012). The leading questions:

(i) Where are we going?
(ii) Who gains and who loses, and by which mechanisms of power?
(iii) Is this development desirable?
(iv) What, if anything, should we do about it?

can inform and structure the transdisciplinary discourse between scientists and non-scientific actors.

A catalytic research team has the mandate to explore, empirically test and structure the design, but it does not need to moderate the process itself. In the literature on policy advice, the catalytic task of science is often described by using the term co-creation (co-generation or co-production) of knowledge (Hoppe, 1999; Jull, Giles, & Graham, 2017; Mauser et al., 2013; Polk, 2015; Serrao--Neumann et al., 2015: 98). However, co-creation describes the goal of such deliberation but not the way to accomplish it. Catalytic science compiles the necessary *process* knowledge of how co-creative processes can succeed in the context of the various policy fields in their sequencing and structuring. It does not ignore existing power relations or socio-political contextual conditions, but systematically examines whether a co-creative solution to a problem can be achieved and implemented and, if so, under which conditions and what type of discourse architecture. It is a matter of structural and process knowledge that guarantees a fair treatment of all positions in conflicts and a factually solid and socially balanced formation of judgments in political discourse (Bäckstrand, 2003; Renn & Schweizer, 2020; Rosa et al., 2014: 1788ff.).

In the practical implementation of catalytic knowledge-building processes, in view of the "wicked problems" with their complex impact structures and ambivalent effects that prevail today, there is rarely a single, overriding solution (Sarewitz, 2015; Van der Sluijs et al., 2008). Rather, such processes can produce a whole range of options for action with option-specific profiles of desired and undesired effects, which can then be weighed against each other in the respective political arenas. Instead of a consensus on the best possible option for action, there is then consensus over dissent, i.e. a differentiated range of functionally equivalent options that all have positive and negative implications. Depending on different views of what is morally superior and more socially desirable (trade-offs between conflicting goals), several solutions may compete with each other (Seager, Selinger, & Wiek, 2012). Thus, for example, options for energy system transformation that primarily emphasize security of supply may include other policy instruments than options that attach particular importance to climate protection and behavioral adjustments. It is then a question of political preference which of these options is to be implemented in concrete terms. The catalytic concept of science has the task of researching and reviewing the architecture for such discourses for handling complex problems and of incorporating this knowledge into political discourse (Renn, 2019c). Several authors within the domain of transdisciplinary studies and many scholars of deliberative democracy have developed and partially tested guidelines and navigational tools for structuring, designing and evaluating discursive processes that combine scientific methods with deliberative procedures (Bryson, Quick, Slotterback, & Crosby, 2013; Breckon, Hopkins, & Rickey, 2019; Bergmann et al., 2005; Lang et al., 2012; OECD, 2020; Pohl & Hirsch Hadorn, 2007; Serrao-Neumann et al., 2015; US-National Research Council, 2008). Especially in a time when political populism and simplistic claims to truth are gaining more and more weight, a counter-movement that builds up institutional, organizational and process-related knowledge for an adequate treatment of complexity, uncertainty and ambiguity is of particular importance (Bago, Rand, & Pennycook, 2020; Mcintyre, 2017: 156ff.).

The catalytic concept is particularly important for issues that involve long-term planning and problems with implications for future generations. First, it provides procedural skills and expertise to regional or national foresight processes that are directed towards the development of robust scenarios for regional or national transformations towards a sustainable future (De Hoyos Guevara, Zugasti

Garostidi, & Alegria, 2019). Second, catalytic structuring can provide a process architecture that explicitly include voices that serve as trustees for future generations. Thirdly, catalytic processes are based on multi-dimensional or multi-attribute decision-making involving multiple stakeholders and objectives that include future impacts of present policies (Renn & Schweizer, 2020).

How realistic is this perspective? Simple appeals to deliberative discourse are obviously not sufficient to integrate a catalytic role into an existing institutional framework. There are, however, many actors, especially in the sub-political sphere, who are not only interested in such discourse, but also want to actively promote it. I myself have been involved in several serious attempts to play out a catalytic role in several deliberative policy making arenas. A concrete example from the energy policy field is described in Box 1. The case study shows that even in times of fake news and populists striving for power, it is possible to shape a successful deliberative discourse on energy system transformation, provided that the necessary catalytic preparations are made.

Like the other two concepts, the concept of catalytic research also has a number of problems and deficits. First of all, it only collects and organizes the expert knowledge without contributing to the substance of the issue in question. Catalytic research is therefore dependent on at least one of the other two concepts (curiosity-driven or goal-oriented) to bring relevant expertise into the process. Secondly, the generation of process and structural knowledge to shape discourses that are appropriate to the subject matter and reflective of the underlying values and interests is particularly context-dependent and makes it difficult to provide universally valid

Box 1
Case study BEKO for a deliberative discourse design.

In the case of the BEKO project, the focus was on the discursive definition of political measures for integrated climate protection in the German State of Baden-Württemberg (Carius, Hilpert, Ulmer, & Wist, 2016; Renn, 2014). The project was commissioned by the State government as a means to introduce elements of deliberative democracy into the policy making context. The approach is hence in between consultative and truly bottom-up participatory (Mobjörk, 2010; OECD, 2020). The approach was inspired by the modular concept developed in this paper:

Curiosity driven research: In a first step, scientific experts were commissioned to assess the effectiveness of possible climate protection measures and to prepare a list of measures together with an assessment of their expected positive and negative impacts. The list comprised a total of 110 measures.

Goal oriented research: In a second step, different groups of energy experts and practioners (entrepreneurs, managers, utility experts, representatives of unions and environmental groups) were requested to further process these scientifically gained findings and enrich them with their own knowledge and experience. The goal was to develop a set of options and strategies to reach a significant reduction of Co2 emissions in 2030 and 2050.

Catalytic research: A group of communication and participation specialists (under the leadership of the non-profit company Dialogik) developed a deliberative design that consisted of the following components:

- Online evaluation: From 17 December 2012 to 1 February 2013, all citizens of Baden-Württemberg were able to comment and evaluate the 110 measures individually on a specially created website.
- Stakeholder evaluation: 120 representatives of important associations met at seven round tables on thematic topics (such as mobility or industrial heat use).
- Citizen assemblies: Around 180 randomly selected citizens met in 29 meetings and jointly developed a document with a total of 1082 recommendations.

In the end, the representatives from the scientific community, the round tables, the citizens' forums and the Internet forums met for a joint workshop to discuss the measures together, to draw up a list of consensual recommendations and a list of measures that continued to be controversial. Scientists were invited as "witnesses" to discuss both functional connections and strategic considerations with the participants in the discourse. The aim was not consensus at any price, but a "consensus on dissent", i.e. a list of measures with solid justifications for and against each measure, based on evidence-informed factual insights and transparency about different values and preferences.

On 2 May 2013 the results were handed over to the Minister for Environmental Protection, Franz Untersteller. Following this participatory process, the Ministry spent about three months preparing and examining the recommendations. A detailed statement was prepared and sent to all stakeholders and participants. After six months of further deliberations, a climate protection plan was officially promulgated on 31 July 2013. The plan included the proposals made by the experts, stakeholders and randomly selected citizens that were part of the process. In 2018, the process was awarded the prize for the best participation project in Germany in the category "regulations" in an open competition for exemplary citizen participation.

In 2019, the State of Baden Württemberg decided to start a second phase of the project called BEKO II to use the same procedure of including randomly selected citizens, stakeholder organizations, and interested internet users to adjust the climate protection plan in the light of the Paris agreement and the Government's intention to be climate-neutral in the year 2050. More emphasis will be given this time to include young people as a major group that will be affected by climate change. The new process has not yet started and will begin in Mid 2021.

insights that go beyond the individual case (Brandt et al., 2013; Giri, 2002; Pohl, 2011; Zierhofer & Burger, 2007). Therefore, the development of a systematic knowledge base depends on the compilation of empirical case studies and interpersonal experience.

The concept of catalytic research seems to overlap with the term "transformation or transformative knowledge", which is frequently used in the debate on transdisciplinary approaches to link knowledge and action (Brandt et al., 2013; Hirsch Hadorn et al., 2008; Van Kerkhoff & Lebel, 2006). Transformation knowledge refers to knowledge that guides actors on how specific objectives derived from orientation knowledge can be transformed into strategies for transformations.

There is a fundamental difference between the concept of transformation knowledge and the concept of catalytic research. Transformation knowledge is designed to demonstrate feasible pathways to translate a desired transformation into actions. However, in the case of a large number of competing transformations this goal cannot be clearly determined without referring to a normative discourse on policy priorities. In addition, transformation knowledge is hardly separable from goal-oriented expertise, which is also meant to design strategies for predetermined goals. Catalytic knowledge, in contrast, is aimed at finding out how to design and implement processes for evidence-informed and value-responsive discourses within a democratic institutional structure. This can refer to any transformation or policy goal introduced by actors in the discourse as long as the process is based on the rules and structures of deliberative discourse. This makes the catalytic concept particularly valuable for designing policies to deal with future challenges and impacts as it does not specify the goal in advance but designs effective and fair discourse procedures to co-determine mid-term and long-term goals and develop scenarios for reaching these goals (assisted by the other two concepts of scientific research).

3.4. Synopsis of the three concepts

In short, the three concepts of scientific research (curiosity driven, goal-oriented and catalytic) complement each other, have overlaps at the margins, but are not functionally equivalent. They are, as explained in the next section, modules of a comprehensive transdisciplinary understanding of science. In Table 4, the essential characteristics of the three concepts are summarized in compact form.

4. Transdisciplinarity as an integrative hybrid of the three concepts

How can this triad of curiosity-driven (disciplinary and interdisciplinary), goal-oriented and catalytic research concepts be integrated into the concept of transdisciplinarity and how can this integration address the problems and shortcomings mentioned in Section 3.4?

The three concepts of research complement each other and constitute analytically separate but closely intertwined modules in the process of co-producing knowledge, developing options for policymaking and generating normative orientations. All three research concepts are constitutive for the transdisciplinary exchange between science, society and politics.

Each of the three concepts has been described (in different terms) and postulated in the rich literature on transdisciplinary research (for example: Bergmann et al., 2005; Engels, Pfotenhauer, & Wentland, 2019; Lejano & Stokols, 2013; Popa et al., 2015; Serrao--Neumann et al., 2015; Thompson Klein, 2015). However, the novel aspect here is the modular structure of combining the three components rather than trying to develop a unified approach to transdisciplinarity (cf. also the critical remarks to the claim of unity in Brandt et al., 2013; Ramadier, 2004; Thompson Klein, 2013). It is also not a merger of multi- and interdisciplinary research with stakeholder inclusion as it has been advocated in several conceptual papers on transdisciplinarity (Ramadier, 2004: 437; Scholz & Steiner, 2015; Von Wehrden et al., 2019). The synthesis of the three orientations: curiosity-driven, goal-directed and process-related preserves the (already established) methodological and quality standards that are valid for each of the three concepts, provides perspectives and manageable tasks for scholars working within the three concepts, including career paths for young scientists[7], and still meets the demands and quality criteria for transdisciplinary research as outlined in the literature that I had reviewed above (in particular Belcher, Rasmussen, Kemshaw, & Zornes, 2016; Jahn, Bergmann & Keil 2012). More specifically, this modular approach brings about the following advantages:

First, it is crucial for transdisciplinary discourse to examine truth claims with the authority of the sciences and to differentiate "fake news" from "true news" in a deliberative setting (Bago et al., 2020; US-National Research Council, 2012). In addition, curiosity-driven research teams are needed to provide the discourse participants with the appropriate factual knowledge according to scientifically recognized standards and to respond to factual questions that participants may raise. Here, the ideology-critical function of science is crucial: to uncover misjudgments based on wishful thinking, intuitively plausible but often misleading rules of thumb and plausibility assumptions, and to share these critical insights with all parties involved in the discourse (McIntyre, 2017: 163f.; Renn, 2014; SAPEA. Science Advise for Policy by European Academies, 2019: 25f.).

Secondly, the transdisciplinary discourse thrives on the targeted knowledge of experts who point out realistic ways to achieve the goals sought by politics, business and non-governmental organizations (NGOs) and develop policy options that promise to be effective in light of the goals that the participants want to accomplish. They develop strategies together with the discourse participants. At the same time, it is there mandate to point to the possible positive and negative side effects that each strategy is likely to produce. The associated goal-oriented research is closely aligned with the problems to be solved and, especially in complex and uncertain decision-

[7] A unified transdisciplinary research concept has also been criticized as putting too many demands and requirements on the shoulder of individual scholars. An almost humorous but very telling account of this excessive demand on individual performance in transdisciplinary research can be found in the article: 'Now I'm not an Expert in Anything' (Aslin & Blackstock, 2010).

Table 4
Three concepts of scientific research for policymaking purposes.

Concept	Curiosity-driven	Goal oriented	Catalytic
Knowledge Type	systematic	instrumental	processual
Function for policymaking	orientation (enlightenment)	problem solving	co-creation
Forms of expression	analyses (causal/functional)	scenarios/options	process architecture
Limits and problems	coping with complexity	goal fixation	Lack of universality

making contexts, helps to design scientifically robust options for action and to assess their consequences (Cash et al., 2002; Lentsch & Weingart, 2011; Miller et al., 2014: 240).

Thirdly, transdisciplinary processes are based on a deliberative discourse involving all relevant groups in addition to scientific experts. This discursive treatment for designing policy options is necessary because of the uncertainty, ambiguity, and frame-dependence of scientific problem descriptions. Non-scientific actors have valuable experiential or local knowledge to contribute and they are often the best judges of what knowledge is relevant for addressing the problem at hand (Mobjörk, 2010; Polk, 2015; Renn, 2010: 111). In addition, the ever-increasing diversity of evaluations, beliefs, interpretations, and value judgments requires a discourse that promotes integration and resolves conflicts (Lawrence & Després, 2004: 403; Witmayer & Schäpke, 2014). Organizing such discursive processes of acquiring and sharing relevant knowledge and embedding it in an argumentative discourse based on weighing each argument and reflecting on common values and interests lies at the heart of a transdisciplinary process. How to ensure the high quality of such a process and how to integrate the scientific communities (curiosity driven and goal-oriented) as well as stakeholders and representatives of the public in such a discursive setting is literally a science in itself, which justifies to distinguish the catalytic function as a distinct research concept. Catalytic expertise provides evidence-informed and experience-based instructions for designing a discourse architecture that increases the probability of accomplishing the main goal of transdisciplinarity, which is to find scientifically valid, socially negotiated, environmentally sustainable and morally superior options for dealing with wicked problems (Head & Alford, 2015).

Fourthly, the integration of the three research concepts also serves the goal of improving present planning processes for mid-term and long-tern policymaking. Methods such as Horizon-Scanning or Foresight rely on discursive processes that are designed to accomplish two purposes: integration of those persons or entities that will be affected by the chosen policy option and including the best knowledge for anticipating future events and contextual changes (Carney, 2018; UK Government Office for Science, 2017). Both conditions are met when the three concepts are integrated. The best knowledge about complex future development is provided by curiosity driven approaches, the dynamics of impacts over time are crucial aspects considered in goal-oriented research and the inclusion of all potentially affected humans and entities is guaranteed when designing discourse processes inspired by the catalytic research concept.

In my view, the integration of the three concepts (curiosity-driven, goal-oriented and catalytic) into processes of deliberative policy-making is the essential contribution of the sciences to promote transformations towards more sustainable futures or towards other desirable transformations. Such processes require more than scientific knowledge. It is precisely a characteristic of transdisciplinary approaches to integrate knowledge from different sources and areas of experience (Despres et al., 2004; Lang et al., 2012; Pohl et al., 2010; Scholz, 2017). In this respect, most scholars devoted to transdisciplinary research agree with the proposition of integration that is crucial for my concept of transdisciplinarity. But how this integration is to be shaped epistemically, organizationally and procedurally is a new task for science, in this case its catalytic mandate. Moreover, in deliberative discourses, robust causal or functional elements of knowledge as well as strategic options for achieving predetermined goals or solving problems are urgently needed, in particular if problems are complex, laden with uncertainty and ambiguity, and potential solutions are highly contested in society. To ignore scientific insights in those circumstances is normally an invitation to disaster. Replacing robust knowledge by power or interests or being guided by wishful thinking have rarely helped to address any problem in an effective and fair manner (Hirsch Hadorn et al., 2006; Weingart, 2000; Zierhofer & Burger, 2007). At the same time, however, social experience, local familiarity, interest- or value-based judgements, social preferences, and cherished routines are important elements of any policy and those elements are best contributed by non-scientific actors (Cash et al., 2002; Knapp et al., 2019). Transdisciplinary science is thus not a monolithic block. Nor does it require a fundamental reorientation of the sciences. Rather, in my understanding, transdisciplinary science is a synthesis of different modules, each with a clear orientation, function, and methodology. These modules can be integrated into transformative discourses and thus represent an important and irreplaceable contribution to complex policymaking.

5. Summary

Policymaking for dealing with wicked and complex problems requires a robust knowledge base for the assessment of the likely consequences of each policy option and is based on balancing conflicting goals considering the diversity of interests, preferences and values of society. This requires a better integration of scientific expertise for informing policymaking, so that the relevant knowledge base can be used in the preparation of evidence-informed, socially acceptable and morally substantiated decisions. The best way to inform policymaking is by implementing transdisciplinary research methods. Transdisciplinarity becomes manifest in the systematic integration of classic curiosity-driven research (disciplinary and interdisciplinary), goal-oriented strategic research (impact assessment of different options); and process-related catalytic research (deliberative integration of knowledge, values, interests, and preferences). The defining characteristics of transdisciplinarity, namely, the systematic perspective, the orientation on complex real-world problems and the inclusion of non-scientific knowledge, are inherent to this kind of research process (Despres et al., 2004: 472; Jahn et al., 2012: 8; Pohl, 2011: 619; Thompson Klein, 2013: 190; Zscheischler & Rogga, 2015: 29).

To meet these characteristics requires an organic synthesis of the three research concepts described in this article. The curiosity-driven concept brings in the systematic insights to make policy options effective, the goal-oriented concept develops strategies to achieve the desired objectives or to constructively address problems that need public attention, and the catalytic concept delivers the institutional architecture and communicative design necessary to successfully conduct a deliberative discourse between and among the various knowledge carriers and users of knowledge.

The synthesis of these three concepts into an integrative approach of building bridges between knowledge and collective action corresponds to the transdisciplinary mission of science. Transdisciplinary approaches integrate process-related, factual, and strategy-related knowledge and ideally lead to a problem resolution that is factually convincing, argumentatively consistent, morally substantiated, and, in principle, acceptable to all.

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