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The Normative Dimension in Transdisciplinarity, Transition Management, and Transformation Sciences: New Roles of Science and Universities in Sustainable Transitioning

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Abstract: This paper discusses the role normative aspects play in different approaches of science–practice collaboration, in particular as action research, (Mode 2) Transdisciplinarity (Td), Transition Management (TM), and Transformative Science (TSc). We elaborate on the different roles that scientists in these processes play. They work as facilitators (or contribute to a facilitated Td process), as activists (i.e., activist researchers) in TM projects, and as catalysts in TSc. Td processes develop socially robust solutions for sustainable transitioning and impacts on the science system through mutual learning and by integrating epistemics (i.e., ways of knowing) from science and practice and focusing on the empowerment of stakeholders. Science is viewed as a public good aiming to serve all key stakeholders. Researchers involved in TM projects strive to influence ongoing transition processes by actively engaging and participating in them, including lobbying for and empowering transformative changes toward sustainability based upon the researchers' own analyses and world views. The TSc approach takes a catalyst perspective of the scientist's role in inducing processes of strategic (societal) transition when including certain stakeholder groups. The paper focuses on what roles normative aspects play in the different approaches and new societal demands imposed on science and universities. Based on this, we conclude that a new order of universities, public knowledge institutions, and boundary institutions is forthcoming.

Keywords: transdisciplinarity; transition management; transformative science; normative issues in science; societal demands; roles of scientists

1. Science as a Change Agent

Historically, the roles and functions of science in society have varied. For example, there "was little place for science in Rome and none in the barbarian kingdoms of western Europe" [1]. Science played a key role in the first Industrial Revolution, but after World War II, we were "witnessing the beginnings of a world science, transforming old and creating new industries, permeating every aspect of life" [2]. Against this backdrop, Erich Jantsch introduced the concept of society as a user or client of science. He suggested that "the university will have to adopt a new purpose which may be recognized as a means of society for continuous self-renewal" [3]. In his opinion, transdisciplinarity (Td) should become a purposive branch of science following a multi-goal and multi-level mode of practicing science directed toward a "common goal" Jantsch suggested and even designed a transdisciplinary university.

The discussion about Td developed in the course of the environmental research that emerged in the context of Agenda 21 and the Rio Declaration of 1992 [4]. The environment became a dominant theme for change and planning. For example, in 1991, the Swiss Science Foundation launched a program of 'directed research' with the added value gained by relating and integrating different ways of knowing from practice and science. At the end of this program, the paper "Transdisciplinarity between funding/promotion and being over-challenged" [5] sketched not only visions but also several barriers Td is encountering in the science system. The Zurich 2000 conference [6], with 300 practitioners and 500 scientists participating in 20 mutual-learning sessions [7] and 12 dialogue sessions [8], presented a definition of what is meant by (Mode 2) Td and focused, in particular, on the integration of epistemics from science and practice for the goal of sustainable transitioning.

Science and higher education have become change agents for sustainable transitioning [9]. Thus, a social normative aspect has intervened. Given that the concept of sustainability has entered national constitutions in many countries (e.g., in Switzerland in 1997), sustainability became a framing concept and a regulating idea of human action [10]. Perhaps there is greater freedom in regard to sustainability than there is regarding human rights, as the specific goals of sustainability have to be developed (and are ill-defined), whereas the meaning of torture seems to be more consensual [11].

With respect to these issues, the paper is structured in the following way. Section 2 provides descriptions of three main approaches: transdisciplinarity (Td), Transition Management (TM), and Transformation Science (TSc). The discussion, Section 3, focuses on the difficulties these approaches face in order to properly cope with the normative dimensions in the current science system. Finally, the conclusion section refers to a differentiated inclusion of normative aspects and political agendas in public science institutions.

2. What Roles Might Science Play in Societal Transitions?

2.1. Methodology and Validation Strategy

This paper discussed Td, TM, and TSc as prominent approaches dedicated to sustainable transitioning. The author of this paper knows Td very well as he has been a main promoter of the Zurich 2000 conception of Td since 1993. The descriptions and analyses of TM and TSc are based on extensive literature searches and constructive in-depth joint discussions with key promoters of TM (e.g., Derk Loorbach and Uwe Schneidewind). To avoid an unbalanced treatment of TM and TSc, a kind of iterated convergent validation was applied. A first complete draft of the paper, including the analysis and classification of approaches, was sent to key promoters of TM (Derk Loorbach and Uwe Schneidewind, who included Karoline Augenstein) with a request to identify (i) "statements which are wrong"; (ii) which were "considered weird, unfair, too biased" [12]; and (iii) which were unnecessarily harmful to present institutions. All three of these representatives responded with intense reviews, mostly constructive; corrected phrasings in the text; and participated in the construction of the labels before the submission of the paper. Further, one of them acted as (a self-declared open) reviewer for in the peer-review process, in addition to an anonymous reviewer.

2.2. Transdisciplinarity: Science as a Public Good

The Zurich 2000 Conception of Transdisciplinarity

Td processes include representatives of all stakeholder groups, and Td is based on fundamental principles of basic Western democracy, such as a pluralistic perspective the principle of "accepting the otherness of others". Within the Zurich 2000 conception of Td [6,7,13], science is considered a public good that serves all stakeholder groups operating within the framework of human and constitutional rights. This compels science to play a special role as a societal institution that contributes to the knowledge necessary to maintain the viability and development of all core layers of society and humanity. The special relationship between science and multi-stakeholder discourse is presented in Figure 1. Three main streams should be involved in a Td process in the case of sustainable transitioning of the (global) phosphorus cycle. We distinguish among (A) a targeted interdisciplinary process in which the knowledge from social, natural, engineering, and humanity science is involved;

(B) a mitigated multi-stakeholder discourse for a case study on (global) sustainable phosphorus management in the Global TraPs project [14] that includes representatives from all key stakeholder groups; and (C) a (professionalized) facilitation relating these two streams under a co-leadership model from science and practice [15–18]. We suggested that these processes should become the subject of (professional) facilitation.

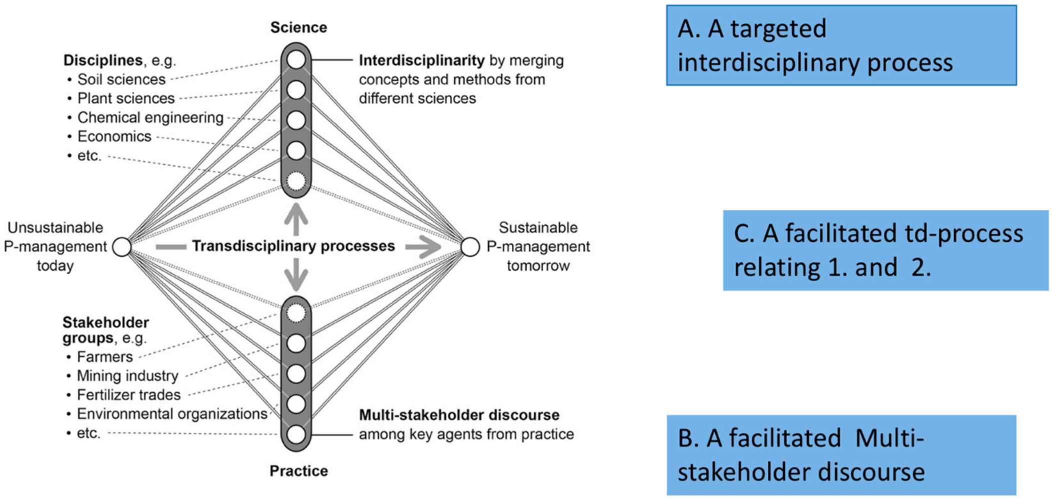

Figure 1. Substreams of a Td process (Figure taken from [17]).

Td processes aspire to serve all stakeholder groups based on the democratic framing of society, and Td can be considered a democratic "policy-tool development for the implementation of sustainability" [19]. Td projects are—ideally—co-governed by a democratically legitimized decision maker (e.g., a lord mayor) and scientists on an equal footing, and they include the knowledge and values of all concerned (see Figure 2). The selection of the representatives of key stakeholder groups is based on a comprehensive system model that allows participants in the process to deal with critical issues that have been included in a guiding question [15,20–22]. The guiding question and the system model are identified in a process that emerges from the initial views of the science and practice leaders (see Section 2, Figure 2), and they are developed in a sequential process that includes representatives of all relevant groups that may affect, are affected by, or are interested in critical system changes related to the guiding question.

From their beginnings, the ETH case studies were dealing with the sustainable transition of urban and rural systems [21,23]. Although in addition, the development of sustainable strategies by the Swiss Railways Company [24] and policy strategies, e.g., for nuclear waste management, have been subjects of Td processes, such as biogeochemical cycle management in the case of phosphorus [14].

Marks and Scholz [25] stressed the necessity of applying methods of knowledge integration, and they suggested the formation of Td colleges in which science and practice work together to develop strategic knowledge about sustainable transitions in a protected discourse arena. In fact, a large number of methods for representing, evaluating, and transforming real-world cases were adapted and applied in many Td processes [20,22,26,27].

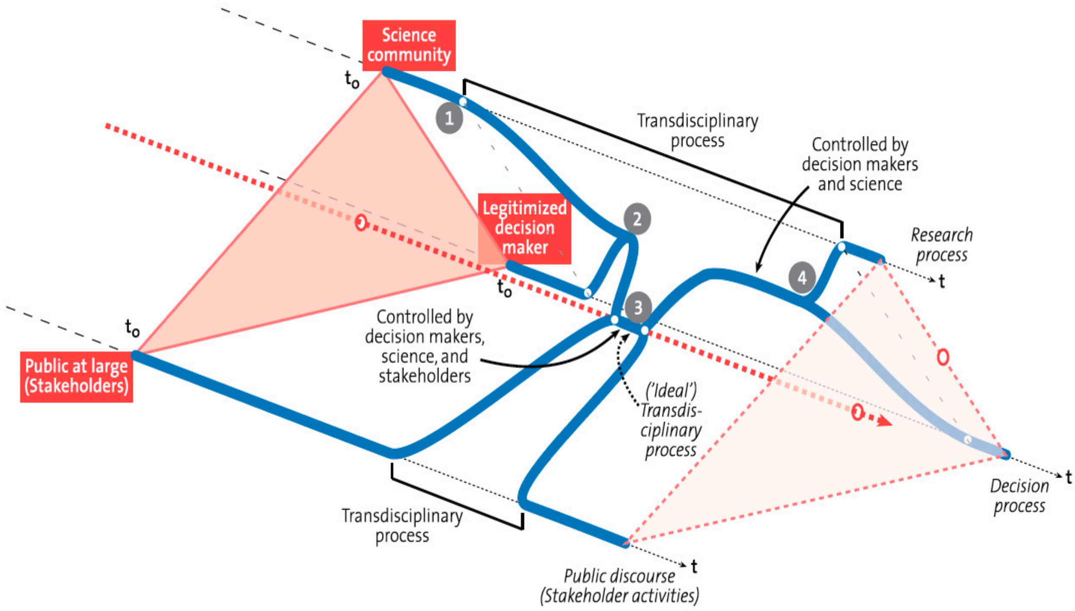

Figure 2. Science, legitimized decision makers, and the public at large (civil society, including different stakeholders) follow different objectives (see right end of the time scale) involved in a transdisciplinary process (figure modified from [28]).

From their earliest beginnings, Td processes [22] have been dedicated to sustainable transitioning. For understanding scientists' conceptions of sustainability and to better distinguish between the normative and societal dimensions, Laws et al. [29] investigated the notion of 21 projects that were run jointly at the Massachusetts Institute of Technology (Boston), ETH (Zurich and Lausanne), the University of Tokyo, and Chalmers University of Technology (Gothenburg). This investigation led to the notion that sustainable development is a proactive, ongoing inquiry (i.e., multi-stakeholder and interdisciplinary process; see Figure 1) on system-limit management (i.e., on preventing hard landings and collapses of valuable systems) in the framework of inter-and intragenerational justice (see Figure 3). Naturally, the social norms and values of the stakeholders also affect what the inquiry—i.e., the process of sustainable transitioning—looks like. We may consider this definition a systemic variant of the Brundtland definition [30], which distinguished between a facilitation process, a science-based resilience analysis and assessment, and a normative, justice-based dimension.

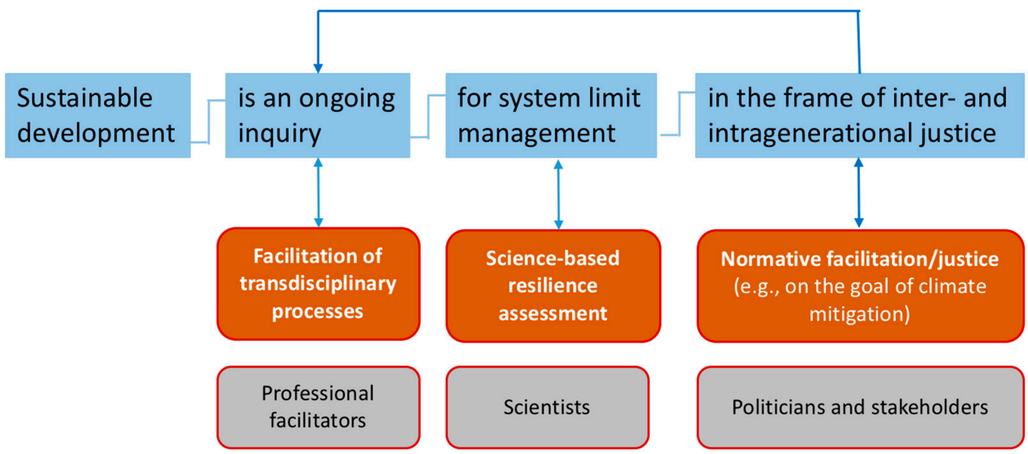

Figure 3. Definition of sustainability (based on [29]).

2.3. Experimental Action Research as a Predecessor of Td

Although this was actually noticed late, the Zurich 2000 conception of Td has strong roots in Kurt Lewin's experimental action research [31,32]. Lewin has long been known as the founder of social psychology [32,33]. Here, the controlled study of changes in environmental settings and impacts such as a change of leadership style or decision rules on action and behavior are key issues, and the systematic variation of environmental settings by analysis of variance (ANOVA)-based designs is the core method. A recent study applied this technique to quantitatively evaluate the success of Td processes [34]. Lewin applied ANOVA to explore and validate the changes in programs and societal settings (e.g., teaching strategies) that could help solve problems faced by minorities (e.g., how to actively include more black students). The area development negotiation (ADN) method genuinely refers to Lewin's ideas. Here, different stakeholder groups are included in designing scenarios for creating future urban settings. The consent and dissent of different stakeholder groups with respect to different aspects (criteria) are assessed by an ANOVA-design-based experimental study (which is included in a Td process). This, then, may become the subject of a mediated negotiation process [35] in order to balance human needs and interests. The ADN method, which is a combination of scenario formation, multi-criteria decision-making, and negotiation [23], became a standard method of Td processes [20].

However, most remarkably, Lewin's cooperation with firms, as well as with organizations active in community work, education, and minority problems within and beyond Boston [35], was institutionalized as the Center for Group Dynamics at MIT, where students could attain a Doctorate of Philosophy in Group Psychology. This is similar to the case at ETH, where a Td Laboratory [36] developed from a Case Study Laboratory. Unfortunately, action research was discontinued at MIT after Kurt Lewin died early in 1947. However, Lewin's ideas continued to develop in the US as differing variants of action research and particularly in participatory action research [37,38] and community-based participatory research (CBPR) [39,40], which dealt with questions of health and education (several variants of action research are presented and discussed below).

Td and action research differ in a couple of respects. As indicated by its label, action research focuses on direct action, and, in many cases, the researcher is intrinsically motivated and takes on the roles and values of a specific stakeholder group. The goals of transdisciplinarity, however, are as follows:

a) capacity building between science and practice by mutual learning and the capacity building of all stakeholder groups;
b) consensus building (particularly in the problem-definition phase) among scientists and practitioners;
c) finding strategies of mitigation among winners and losers of transitions; and
d) the legitimization of certain actions by politicians who may refer to a balanced process of finding socially robust orientations.

Thus, Td goes beyond mere problem solving and "solutionism" [41], yet it also aims for the goal that scientific disciplines and the science system itself will benefit from the theory–practice collaboration. The Global TraPs project may be taken as example. Researchers, together with key practitioners (from the mining industry, geological surveys, and fertilizer producers), developed a differentiated view regarding the scarcity of the finite resource phosphorus [42–44], which corrected unreasoned concerns about short-term scarcity of this resource. Without the data and knowledge from practice, this scientific progress would not have been made.

We should note that Td is an approach developed mostly in German-speaking countries and in Sweden but has become acknowledged at high-level universities worldwide [45–49]. It became a subject of strategic planning for ETH [50] and a method of research in strategic resources management [51].

2.4. From Science to Policy: Transition Management

The TM approach developed at the end of the 1990s in the Netherlands in the context of a policy–science debate about long-term environmental policies based on the work of Jan Rotmans on integrated environmental assessment and modeling on transition processes in environmental systems [52–54]. This approach to a large-scale, long-term perspective was influenced by, among other things, innovation theory and adaptive complex-system thinking [55,56]. The models included political actors and decision makers, and the scientific results were addressed to them. The idea to contribute to "coherence and consistency in public policy" led to the conception of TM [57].

Starting from a long-term, multi-domain, multi-actor perspective, TM attempts to influence the speed and direction of transitions by creating arenas for actors who want to contribute to sustainability transitions. This may be considered a proactive governance approach that develops shared strategies, visions, and actions, yet is done, however, by a "selective participation when leaving the dominant interests out" [58] of a subset of actors. While grassroots processes and participation have also been identified as meaningful strategies, it sometimes referred to policy consultancy and the Dutch Triple Helix conception [59], in which science interacts with leading representatives in politics and industry in a flexible manner. Although there are not yet methodological tools available such as those for Td [20,27,60], recent work has provided insight into how the interaction between scientists and practitioners is conceived [61]. The strategy involves, rather, "influencing transitions" [62], by supporting processes of framing, visioning, strategizing, and experimenting in society. In addition to this, TM explicitly acknowledges the inevitable impact researchers have as part of transition contexts and processes requiring a reflexive attitude. By actually becoming one of the actors in a transformation, the aim is to achieve a real-world impact as well as to develop in-depth insights into actor motivations, governance processes, and the impact of interventions [58,63]. A rationale for this is that researchers have to be in the place where transitions happen and produce insights into the manageability of sustainable transitions [56].

From a systems perspective, the focus is on the interaction of social and technological systems. For this type of coupled system, three layers are identified when referring to ecology: a framing-landscape level, a regime level, and a micro level of niches. Niches are places in which new cultures, structures, practices, and technologies develop as alternatives to the mainstream. They are embedded in rather stable regimes of actor networks, rules, and technological infrastructure. The top level, landscape consists of large-scale external trends and changes in society that are considered robust for opposing strategies of single-actor groups [64]. Regimes are the dominant configurations of institutions, implicit rules, technologies, discourses, and behavioral rules. Transitions result from the interplay between landscape pressures, internal regime tensions, and increasing niche competition. Figure 4 presents a governance framework that emerged from these perspective four types of governance processes of TM [65]. This multi-level model has been widely received and works successfully as a cultural tool in many domains, including adaptation to climate change through the transitioning of energy systems. The "heart of the Dutch transition approach is transition platforms consisting of people from business, academia government, and civil society [providing] proposals for transition paths to the Dutch government and public" [66].

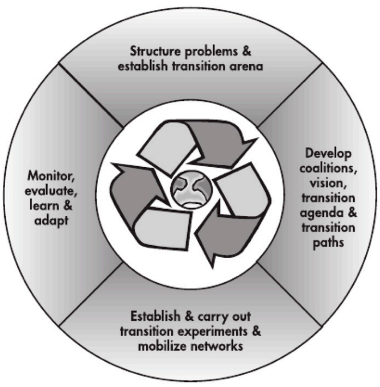

Figure 4. The transition cycle of the TM approach [65].

Some years ago, the Rotterdam TM approach took a stronger activist approach based on the analysis that some societal regimes need disruptive transformations. The rest of this subsection refers to Loorbach's paper [67], wherein a conception of science is developed that departs from disciplinary structures (p. 79) when taking a "postnormal science and action orientation" (p. 68) that "is normative" (p. 68) and aims "to influence" transformative changes while studying them" (p. 68). The new conception, which is rooted in qualitative analysis rather than based on integrated modeling, puts the normative component and the third mission of science (to contribute to societal problem-solving) on top and switches from an evolutionary [57] to a revolutionary view of long-term transitions. Loorbach states that reflexive modernization (p. 23) has come to an end, and even "Sustainable Development itself has become part of the problem", as the foundations of modernity "are systematically unsustainable" (p. 32).

TM becomes "activist research" (p. 67). This requires that more funding be allocated according "to the ability to show societal value rather than on the ability to satisfy reviewers" (p. 72) and not only to contribute to consistent and coherent knowledge or other criteria of normal sciences. Loorbach introduced the idea of governance panarchy, referring to Hollings's theory of succession biology [68], in which (over-)mature systems collapse, and to anarchist political theory [58]. In this fundamental transition, the idea of science as a public good, which is characteristic of the Zurich 2000 conception (see above), is abandoned, as Loorbach intends to work selectively "with proactive and transformative actors within government, business, science, and civil society" (p. 76). To do this, analogous to the idea of TSc colleges, Loorbach and his colleagues developed a Transition Academy (p. 79).

Historically, the present shift to a critical activist worldview, which considers sustainable development as a patchwork repair that may promote the lock-in of the (Dutch) regime, is a different starting point from the formation of TSc 20 years earlier at the climax of environmental crises and catastrophes such as Chernobyl or Seveso. Today, there is also increasing insecurity regarding global financial systems and large-scale migration. There is a presumption that we are nearing the end of the modern industrial, fossil-energy-based age, the modernization of the Western welfare society (which cannot be extended to a global level), the nation-state ordered world system, and—if we look at science—the end of the segregated mono-disciplinary order of universities.

2.5. Promoting the Great Transition: TSc

The question about the collapse of global civilization has been posed by biologists [69–71] when pointing to the vulnerability of ecosystems and their sensitivity to human actions. It is remarkable that the conventions of Rio [72] targeted the prevention of "dangerous" human interference with the climate system and thus can be viewed as global, environmental precautionary planning [73]. Although the major concerns and consensus were focused on climate change, desertification, and biodiversity, the three-pillar concept of sustainability introduced the social and economic dimensions of future change, development, and scenarios linked this to the concept of what has been called the Great Transition, a term coined by the economist Kenneth Boulding [74] upon noticing the fundamental changes in human resource use. The term was used by the Stockholm Tellus Institute in order to design global scenarios to "examine worlds that transcend reform to embrace new values and institutions in pursuit of a just, fulfilling, and sustainable civilization [75]". The aims of the Great Transition went far beyond resilient ecosystems; they involved a strong Western civilization perspective and targeted "socially equitable, culturally enriched, and ecologically resilient *planetary civilization* [as a] normative foundation [75].

A very similar approach emerged from a business–science perspective of sustainable management developed at the University of St. Gallen's business school, in the course of extending the natural capital-based economic sustainability approach [76,77] by shifting to a specific form of weak economic sustainability characterized by actor–network-based innovations and institutional changes [78]. When referring to ideas about new institutional economics [79,80], one core idea is that sustainability calls for a transformation of the explicit and implicit rules and procedures on a societal level. Institutions are viewed as enablers of societal change [81]. This view has been considered a third component supplementing the stakeholder value and normative idea-shaped approaches (which play a prominent rule in Td; see Figure 2).

The idea of (sustainable) "transformation as a democratic search process" became the core message of the 2011 flagship report, "World in Transition", by the German Advisory Council on Global Change, an independent scientific advisory body launched and financed by the German government [82]. The WBGU focuses on critical environmental issues such as climate change, deforestation, and biodiversity; soil and freshwater conservation; and the global food supply as well as population growth, and—still with an optimistic view–the rise of democracy [83] and thus closely resembles the Great Transition. The most salient points in the context of this paper are as follows:

(i) The idea of a "social contract for the transformation to a sustainable society" that launches "responsibility towards future generations with a culture of democratic participation" [84];

(i) The suggestion for "a new scientific discipline—'transformation research'—that specifically addresses transformation processes" and should be based on "systemic interdisciplinarity" and "involving stakeholders on a transdisciplinarity basis," in particular in "identifying research issues and objectives" [85].

The idea of a social contract for sustainable transitioning refers to a modern philosophical, Enlightenment-based idea and was explicitly suggested in reference to Thomas Hobbes (1588–1679), John Locke (1632–1704), Jean-Jacques Rousseau (1712–1778), and Immanuel Kant (1724–1804) and the vision of a "proactive state" as a key actor [84]. The separation of science and citizens' rights are well addressed in the statement: "The task of the scientific community is therefore to identify policy options; it is a matter for the democratically elected decision-makers to decide on the appropriate course of action" [84]. Thus, "research for transformation" should develop, investigate, and suggest "political strategies" [85], e.g., through transdisciplinary processes.

The Wuppertal Institute and its President Uwe Schneidewind [86,87], who is also a professor at a public university, took a leading role in the development of transition science and in the identification of key ideas [88]. The Wuppertal Institute is institutionally a limited liability company and non-profit enterprise (gGmbH) and thus a type of non-governmental institute. However, it was launched in 1992 by the social-democratic government of North Rhine–Westphalia. It received considerable basic (long-term) funding from the state as an Institute for Climate, Environment, and Energy in the early 1990s, when both local air pollution and climate change related to fossil energy were issues. It is thus, by its nature, an interfacial process institute between government and various stakeholder groups. However, the governmental funding has been viewed with resentment by NGO-like eco-institutes [89] that criticize consultancy-shaped projects with governmental sourcing and NGO-like aspirations of transitioning to a new society (similar to the TM approach and in contrast to Td's idea of the public good).

Schneidewind and colleagues' current intention to extend and transform the science system and to build a Mode 3 research model that supplements the societal-problem-driven Mode 2 research. What Mode 3 science really means is fuzzily formulated but relates—as similarly expressed in the TM approach—to "societal transformation challenges", "by actively including civil society actors as an external corrective on the 'blind spots' in the science system" [90]. The core method of Transition Science is the "Real Experiment" [91] in settings such as "Real-World Laboratories" (RWLs). In particular, cities are seen as places of transformation. The practice of RWLs has, thus far, not developed to much extent. RWLs are conceived as "a normatively framed approach within spatial and content-related boundaries, using Td methods of knowledge integration and engaging in cyclical real-world interventions in order to contribute to local action for sustainable development and the empowerment of change agents" [92]. There are four RWL labs in Wuppertal and others elsewhere in Germany.

TS does not look for idealized, artificial settings that isolate ambivalent impacts in order to approach an unobtrusive observation for gaining insights in (multi-)causal mechanisms and systems.

A "real-world experiment" is seen as a hybrid approach, including components of field observation and living experimentation for ecological and technological implementation [88]. We may consider this approach as a vision and perhaps as another replication of the debate that the common method of social science experimentation—manipulating one aspect while leaving all other aspects unchanged—is unrealistic [93] and calls for adapting the setting of observation [94]. However, the validation of data seems to pose many fundamental questions. The major field of application is urban development and the search for social innovation [95]. In 2015, the state of Baden-Württemberg launched seven labs ranging from national parks via energy transitioning, mobility, and space-sharing to the sustainable transitioning of traditional industries such as the textile industry with a clear commitment that "science may find solutions for [the] future only when collaborating with society" [96].

The methods and methodology of real-world experiments are under construction. The promoters of transformative science (TS) refer to the methods applied in Td processes [20,21,60] and to the vision of disciplined interdisciplinarity in Td discourses [97]. However, there are also other questions, such as in what way normative lobbying for new sustainable patterns of life or genuine democratic discourses that include all main stakeholders should be launched or how the inputs of science and practice should be used; these questions have yet to be answered sufficiently by the TSc approach.

2.6. Different Roles of Scientists in the Three Approaches: Facilitator, Catalyst, or Activist (Researcher)

If we highlight those roles that science may play, we can distinguish between two extreme positions. The first is science as a self-efficient endeavor in which scientists write papers that are then reviewed and read by other scientists. This narrow view was promoted by the theme "from professors to knowledge workers" [98]. It appears that, in some domains, craftsmanship-like quantitative records have replaced the quality of ideas generated by sage scholars. A second role is linked to the service function of science and to what we call a "luggage carrier". Science became functionalized by politics or industry, playing the role of a helpmate that performs contract-based research and development, and follows instructions. As Trischler and vom Bruch [99] elaborated, many of the activities of Fraunhofer Gesellschaft follow this model, which resembles the principal agent model. Industry is the principal, and (public) science institutions represent the agent. We also think that some of the ("close to citizen") projects of the Dutch programs Climate Changes Spatial Planning Programme [100] and Knowledge for Planning [101] fall into this category: The task "to support the development" may be seen as scientists serving as helpmates to manage a national political problem, i.e., the "spatially explicit adaptation and mitigation strategies that anticipate climate change" [100]. To avoid becoming dependent on third-hand money and/or losing the independence of science, contract-based research has to be abandoned in Td processes. Instead, Td processes should receive sponsoring (which can be linked to declarations regarding the processes for which such monies may be spent). Yet practitioners must be given full transparency about data and papers before publication in order to avoid being unreasonably or unnecessarily harmed. The latter is usually guaranteed by co-leadership (see above).

Td, TM, and TSc aspire to introduce new ways of doing and utilizing science for societal learning and transitioning. The concepts overlap, but they differ in the conception of the role that science and scientists should play in the transition. Doubtlessly, all approaches see science as a change agent and scientists as reflective and reflexive [63].

Td launches and facilitates mutual learning between science and society when epistemics (ways of knowing) and values (e.g., about the subjects of inquiry) in the processes of joint problem definition, problem representation, and problem transformation develop socially robust orientations. Science functions as a public good and knowledge broker, which should help all stakeholders to better cope with ongoing transitions in a sustainable manner.

TM supports and mobilizes proactively human actors (people, cities, sectors, and organizations) to take action in fundamental changes toward a sustainable future. Scientists are conceived of as a "socially committed, open-minded, curious and—at times—provocative bunch"; they are "critical of the status quo, contribute to fundamental change, and generate sustainable futures" [102]. TM has been closer to politics governmental actors, see [56] than Td, which focuses more on the whole range of policy makers (stakeholders).

TSc "takes an active role in initiating and catalyzing change processes (see Table 1). The aim is to increase[d] societal capacity for reflexivity with regard to fundamental change processes." Such as in TSc, science is conceived as an "an enabler of collective social learning processes" [103] quotes taken from (pp. 2–10). The concept of 'catalyst' falls between the reflexive facilitator and the activist; it conceives of scientists as initiators of change and process facilitators [63].

Table 1. Societal Roles of Science. (This categorization has been developed jointly with Uwe Schneidewind.)

Narrow Understandings of the Science–Society Relationship			
No.	**Key Features of Science**	**Role of Science**	**Short Label of Scientist**
(1)	Science as self sufficient endeavor ("administrative knowledge processing," German: Sachbearbeiter)	Specialized disciplinary work	Knowledge workers
(2)	Science as a lobbyist tool	Contract-based research; social work on higher agglomerated social systems	Luggage carrier (German: Kofferträger)
Enlightened Understandings of the Science–Society Relationship			
(3)	Transition Management: Science as an agent of sustainable transitioning	Scientists as activists	Activist
(4)	Transition Science: Science as a specific form of strategic planning (by transdisciplinarity methods)	Scientists as catalysts	Catalyst
(5)	Transdisciplinarity: Science as public good in democratically shaped societies (transdisciplinarity and reflexivity)	Scientists as facilitators (of efficient knowledge use and reflection)	Reflective facilitators

3. Ambiguities of the Use of Normative Ideas in Science

In order to demonstrate the concerns of disciplinary science with ways that the normative dimension is dealt with in the presented approaches, we sketch a fierce critique of TSc by the president of the German Science Foundation (DFG). In a paper entitled "On the Politics of Transformative Science" [41], Peter Strohschneider criticizes the "normative anchoring" of scientific activity, solutionism (i.e., the issue that science is functionalized as a problem solver), the Td approach that gives some control of a scientific process to non-academic agents, and, related to this, the loss of differentiation and the endangerment of "social contamination" of scientific reasoning and the destruction of the special role of universities in science and what he called "fictitious facticity" (in German, *Faktengewalt*, i.e., the misleading legitimization of policy makers). The latter refers to society expecting push-button solutions, whereas science generates theoretical knowledge that may be applied to many fields.

3.1. Top Academic Institutions' Concerns about Transdisciplinarity and Transition Science

The three presented approaches—Td, TM, and TSc—have come under severe criticism by traditional science. The author of this paper clearly recalls that, around the turn of the millennium, the president of ETH Zurich launched a critical inquiry of the author's work on TSc, questioning whether ETH Zurich should allow this type of work that was conducted on an unusually broad range of topics. The president (initially) had the idea or image that TSc would create something like an "indigenous mathematics" [104], i.e., a simplified folk science for coping with complexity. After a comprehensive and exhaustive evaluation, this opinion was, fortunately, altered, and TSc became an accepted mode of doing and utilizing science in the ETH domain [105].

The TSc approach, which considers itself "a catalyst for a learning society on the way to sustainable development" [106], was criticized by a remarkable position paper entitled "On the Politics of

Transformative Science" [41] written by the president of the German Science Foundation, the philologist Peter Strohschneider, with the heading "On the politics of transformative science" [41]. This paper comprises thoughtful arguments that are worthy of reflection, at least if the institutional structures of the research related to sustainable transitioning are of interest. We first briefly present the arguments; we then show how each one applies in a different way to the three approaches presented and what misunderstandings may be involved in Strohschneider's view.

The starting point of Strohschneider's arguments is the reference to Transition Science and a review of the German Advisory Council on Global Change (WBGU, which was launched in 1992 by the ministries of the environment and of research and technology) for sustainability as a global societal contract. WBGU considers the current fossil-energy-based, world-economic system a "normative untenable (unsustainable; in German, *unhaltbar*) state" [84] The core issue is the norm of intergenerational justice (see Figure 2), which urges a great transformation. Strohschneider [41] focuses on a statement by the [85] claiming that, besides the "self-organising civil society," the "scientific expert community should become a new, important actor" as well. Strohschneider is concerned that the new reciprocal societal contact (i) urges the science system to reorganize itself to align with the issues, subjects, and contents of the societal transformation; and (ii) that societal reputation and the funding of science will focus on this aspect of science.

In some detail, Strohschneider criticizes the following four features of TSc:

- Solutionism: Science becomes directed by an oversimplified problem-and-solution scheme that—among other things—does not sufficiently differentiate the epistemics involved also in medicine and engineering science and how they are used in practice.
- Transdisciplinarity: Strohschneider acknowledges that disciplines create an inner environment (in which, to be specific, scientists write papers that are read and evaluated by other scientists). In contrast, he sees that transdisciplinarity "makes society become an integral part of knowledge production" [88]. Thus, an external reference is seen as becoming the director of scientific processes instead of inner-science rules and processes.
- *Faktengewalt: Faktengewalt* is interpreted as a mechanism by which data (facts) and knowledge are given force and supremacy (see Hoffmann). Strohschneider stresses the "principle of methodological skepticism (in German, *Zweifel*) that differentiates scientific from non-scientific knowledge [41]. He refers to the danger that judgments on societal usefulness or utilitarian arguments are dominating science, and he refers explicitly to the concept of socially robust knowledge [107]. The critical point for the science system is the feedback of the normative sustainability reference to scientific evaluation. Sustainability, which includes normative moral, societal, and (majority-oriented) political components, is overruling the search for scientific validation.
- De-differentiation: The most essential critique refers to the de-differentiation of science. Strohschneider notes that TSc abandons a distinction between science and non-science. Science becomes one voice among others, and it would become obliged to serve sustainability. The charge for a science statement switches "from systemic responsibility to individual (legal) liability" (p. 183). Strohschneider refers to the 2009 L'Aquila Earthquake, the aftermath of which was that scientists, charged with manslaughter, received six-year jail sentences in 2012 because—although given uncertain and ambiguous data—they had not warned the public [108]. This argument, which is brought to the context of the democratizing of expertise and science as well as to features such as "co-design" and "co-production," may be taken as an example of a societal misunderstanding of what a discipline (i.e., geologists) knows about the emergence of a single real-world event (here an earthquake) and what is not known.

Strohschneider's work has been discussed in various papers [109–111]. We briefly clarify several issues with respect to solutionism (Section 3.2), Faktengewalt (Section 3.4), and de-differentiation

(Section 3.3). Then, in Section 4, we deal in some depth with social involvement and the "social contamination of science", Strohschneider's main argument with respect to transdisciplinarity.

3.2. Orientation on Sustainable Actions Instead of Solutions

For instance, this author [97] shifted the Nowotny et al. [112] concept of "socially robust solutions" to "socially robust orientations" ([97]; see Box 1). This was done most often when running a Td process with the Swedish and Swiss nuclear power industry and its stakeholders [113] that called for a sensitive definition of shared and differentiated responsibility and accountability. Scholz distinguishes three different roles participants may play in a Td discourse (see Figure 2), i.e., legitimized decision makers, scientists, or concerned citizens (stakeholders). The term orientation also stresses that mutual learning between science and practice is a basic principle [114]. As presented in Figure 1, Td processes establish a temporary collaboration between science and practice. "Socially robust orientations" are related to real-world decisions, but they are "if–then" types of relationships on actions and impacts that decision makers may learn from and utilize. "If you want to have X, then do not do Y because". The phrase socially robust orientation acknowledges the specific constraints (including democratic compromise) under which real-world decisions are made. Scientists are not democratically legitimized decision makers as are lord mayors or owners of real estate or companies. However, they may help decision makers to improve their decisions as well as the outcomes of these decisions. Actionist approaches such as TM tend to be more direct and also work with recommendations [56].

There are views among transition researchers that call for a direct involvement of scientists in direct action on complex (economic, social, etc.) decisions. Wiek [115], for instance, states that "joint decision-making" among scientists and strategic agents that goes beyond the contextual decision-making process is the ultimate goal, i.e., the highest level. He also criticizes the "normative asymmetry" between science and policy or society and thinks about replacing the "idea of pure science by the idea of concerned science that is not only legitimized but also obliged to contribute to the generation of normative and action-guiding knowledge" [115]. This is definitely a solutionist's perspective, in contrast to the Zurich 2000 definition of Td, which in this point meets the concerns of Strohschneider expressed in his view on Td.

3.3. Differentiation for Efficient Co-Creation

Td of the Zurich 2000 approach takes a clear differentiationist approach with respect to the disciplinary orientation. In particular, scientific disciplines are judged to function as scientific clearinghouses of knowledge, i.e., as a forum in which theoretically incoherent and logically incohesive knowledge providing incorrect or inadequate knowledge is identified and abandoned. The history of science [116] is full of such examples, including incorrect theories about worms causing cancer, which even received the Nobel Prize [117], or the Italian School of Algebraic Geometry, which collapsed after a generation of "brilliant speculation" [118] because of insufficiently acknowledging strong standards of mathematical proof. This is also shared by Schneidewind and colleagues [119], who acknowledged the "rigid quality criteria" of academic disciplines. Box 1 below clearly presents a position that has been shared unambiguously in the Td case studies co-led by the author. Here, Td not only fully supports the inner-science autonomy but also shows how science and societal perspectives, interests, and constraints may well be related. However, as also stressed by Schneidewind, science and practice have different roles. The questions "What may be wrong with this statement under what constraints (e.g., prerequisites, situations, etc.)?" and "By what means may I validate this statement and show that it has to be improved?" are keys to the history of science. This is different from real-world decisions where economic success, feasibility, public acceptance, etc. are key criteria.

Box 1. Definition of Socially Robust Orientation A 'Socially Robust Orientation' [96].

No.	Property
i	Meets science *state of the art scientific knowledge*
ii	Has the potential to *attract consensus*, and thus must be understandable by all stakeholder groups
iii	Acknowledges the *uncertainties and incompleteness* inherent in any type *of knowledge* about processes of the universe
iv	Generates processes *of knowledge integration of different types of epistemics* (e.g., scientific and experiential knowledge, utilizing and relating disciplinary knowledge from the social, natural, and engineering sciences)
v	*Considers the constraints* given by the context both of *generating and utilizing knowledge*.

3.4. The Two-Way Faktengewalt between Science and Experiential Knowledge

Solid scientific findings should influence planning processes, political decisions, and everyday decisions. This holds true even if the state-of-the-art knowledge is false. The example of the fallacious hypothesis that worms may cause stomach cancer, which was awarded the Nobel Price, can be taken as an example [120]. In general, scientific knowledge is complementary to experience and intuitive reasoning. However, scientific knowledge differs from alchemy because scientific methods go beyond myths, magic, and other supernatural aspects of reasoning; yet intuition and experience are superior to analytical knowledge in many situations, in particular, if we are facing problems that are complex, multi-layered, etc. [28,116,121,122]. The latter holds true especially if different rationales, e.g., from natural and social systems, interact. We should mention that this topic has been discussed in high-ranking journals with strong support from practitioners, in particular, CEOs from geological survey and mining companies.

We should mention here that the *Faktengewalt* from practice corrected faulty scientific applications of the Hubbert curve rationale in regard to phosphorus. Here, several scientists proclaimed that supply-based peak phosphorus would be reached in 2030 be [123]. This statement resulted in strong objections by practical experts in mining companies, mineral surveys, etc., as they knew the approximate amounts of phosphate rock that might become economically produced (e.g., with some price increase or more-efficient mining technologies) in the near and mid-term future. There has been a misapplication of a mathematical model when identifying future ultimate retrievable phosphorus resources (which is the total amount of phosphorus that will be mined in the future) with reserves (which are the known, currently economically mineable phosphate rocks that have been assessed and communicated by mining companies). This failure could be corrected by the Td Global TraPs project and its follow-up activities [43,124,125] and shows how the *Faktengewalt* of experiential knowledge can affect science.

4. The Normative Dimensions of Science and Society

Science is a normative venture in many respects, and as such, it refers to (authoritative) oughtness [126] of binding rules, laws, and standards of conduct that constrain actors. For doing this, we distinguish (a) between a societal perspective. We first, in Section 4.1, discuss how (non-scientific) societal norms, interests, preferences, values, laws and constitutions, cosmologies, and academia affect research and its validation and how participation is legitimized. Then, in Section 4.2 we switch to a philosophy of science perspective and ask what concept of science is included in Td, TM, and TSc. Both sections refer to the relationship between science and practice (i.e., stakeholder views) and, in particular, to the question of in what way societal norms should direct scientific work (see Section 4.3). This will be achieved with the use of an extreme example, i.e., Aryan physics, which illuminates how "societal norms" hinder the development of science. We do not deal with the history of planning science in this paper in detail.

4.1. Social Norms Normative of Transitions

The three approaches, Td, TM, and TSc, refer to social norms in different manners. Td refers to the idea of science as a 'public good' and a set of pluralistic values (characteristic of democratic societies), the Universal Declaration of Human Rights [127], compatible constitutions, and other references. Td is seen as a tool of democracy tool (see above). In this sense, the normative social dimension is assigned to the interest, value, and cultural norm-based multi-stakeholder discourse. Td processes are lead (ideally) in a co-leadership with democratically legitimized decision makers. However, this does not mean that the scientist's (personal) norms do not play a role. What societal issue is considered worthy of becoming a subject of Td research or how the process of stakeholder selection is performed is related to the normative (democratic) dimension. This is related to the "Principles on Academic Freedom and Tenure," which was developed by US professors in 1940 [128]. Please note that basic decisions on science funding (which are made on a governmental level) or foundations of (private or public) academic institutions are strongly constraining academic freedom and are normative by nature. This also holds true in regard to if and what transition science is promoted (see below).

The TSc approach (which includes Td processes) does not fully follow the view that all stakeholders (referring to human rights and national constitutions) should be involved but rather focuses on certain stakeholder groups that are considered pioneers and forerunners of sustainable transformation. Schneidewind and Borodowski [106] use the metaphor of a chemical catalyst. When referring to normative societal missions (sustainable transitions), scientists may promote and lobby for specific forms of this transition if they create certain real-world labs and promote certain types of transitions. Thus, scientists' values and social norms are an important factor if we look at the decision to participate in the transition process for TSc.

The TM position is more difficult to understand and to describe, as the conception is under development and has been used differently in recent decades. On the one hand, it is similar to Td, as it is seen as a method of co-creation "where different subsystems are shaping but not determining each other (relative autonomy)," and it links "advantages of incrementalism (based on mutual adaptation) with the advantages of planning (based on long-term objectives)" [129]. On the other hand (see also Section 2.2. above), TM is shaped by a highly critical view of current Western societies in which "sustainability has become a problem by itself" [67] and is used as a starting point to fundamentally question existing regimes and explore radical alternative futures. TM is seen in the light of a new transformation that is, in essence, a "socioeconomic revolution" (p. 35). Thus, panarchy-like, disruptive processes are likely. Scientists need to acknowledge the inherently normative societal role of research and act as participants in transition processes to combine their normative impact with collecting deeper insights, "part of societal networks normative in its orientation towards sustainability" (p. 68). This activist perspective may become linked to a highly selective choice regarding which stakeholders will be involved. This can be seen in the decision regarding which stakeholders will be invited. For instance, Rosendahl et al. [130] decided to "invite only organizations working with and for poor rural groups". This is, finally, a subjective, activist (politically shaped) perspective that calls for careful (participatory) reflection both from an inner science and from a societal perspective [131]. Although we naturally acknowledge that there are certain political systems or research questions that may call for taking a selective strategy, we have to reflect carefully on the impacts of such decisions, both from an inner and a societal perspective. Biased selectivity in science excludes not only certain epistemics and (and legitimate) value systems, but also social facts (in the sense of Durkheim, e.g., the impact of norms can be measured) that may be important from a sustainable transition perspective. From a society perspective, we have to be aware of not becoming (ideological) occupational activists [132], such as the "non-problematicity" proponents who were also devaluing disciplinary work and hindering the clearinghouse and arbiter–honest broker function of science [133].

4.2. Normal vs. Postnormal Sciences

All major proponents of the presented approaches agree that the traditional science system has to be changed. Simplified, the approaches differ in respect to whether an evolution of science is promoted that supplements disciplinary research and interdisciplinarity or whether a revolution of science is promoted with a new positioning and validation of the common science order. The latter is mostly done when referring to postnormal science. For understanding this, a brief look at the history of the philosophy of science is necessary.

In the 1960s, the relationship between science and society as well as the ingredients, objectives, and core criteria of science led to a distinction between "normal science" and "extraordinary or revolutionary science" [134–136]. Simplified, normal science was organized by disciplines that use certain paradigms (i.e., accepted subjects of research accepted by a certain scientific community) and methodologies. Scientific revolutions take place if scientific theories produce anomalous results that are not in coherence with reality or are full of contradictions. Here, we may argue that Td has become a new, third mode of science looking for a new paradigm, as the (socio-technological) complexity of real-world problems calls for new ways of doing and utilizing knowledge. This would require specifying the nature of (normal science) and practical knowledge and appraising or validating its use for certain types of problems [137]. The reference to disciplinary knowledge is taken as a major component of socially robust knowledge (see Box 1i). However, in addition, the anomalies, the relativity, and the limits of disciplinary (normal) science are acknowledged. This is expressed in Box 1iii with the claim that the "unknown" (and what is not incorporated in a disciplinary paradigm) has to be communicated frankly. This leads to the vision of "disciplined (i.e., discipline-based) interdisciplinarity in Td discourses" [97]. We should note that this view is widely shared by the main proponents of the TSc approach.

The TM approach makes a stronger reference to the postnormal science view [138–141], which is often associated with a subjectivist, social constructivist view. This approach relies on Jerome Ravetz's provocative, valuable book [142] and his concept of critical science. In the context of this paper, there are two main messages in Ravetz's original book that are still the main pillars of post-modern science. One is the critique of the "industrialization of science" after WWII (including peer-review controlling) resulting in shoddy, faulty, substandard (quickly written), sloppy (and related to immature theories), and dirty (e.g., by contributing to produce the atomic bomb) contributions. The second is "far less plausible [and] contends that traditional conception of science as an activity in the pursuit of truth, [is] obsolete" [143].

A recent book [144] on postnormal science takes the same route and starts with a critique of the frauds and deceits of scientists, lacking reflection on its limits and the (naïve) aspiration of science to be a "truth-producing machine" [144]. Merton's ideas about the inner science norms of universalism, communality, disinterestedness, and organized skepticism may be widely lost [145,146]. This author is convinced that this critique is partly reasoned and that new strategies are needed in order to maintain the "clearinghouse function" of science [97]. However, the fundamental critique on the loss of the scientific mission of approaching a more realistic understanding of the universe is difficult to share. Science provides theories and models and not a copy of the real world. Every (senior) scientist knows that any scientific theory will be replaced by a better, more adequate one in the course of history [136]. The history of the atom may be taken as example. Any verification calls for meta-levels [147]. As already conveyed by the title of the book How to Lie with Statistics [148], any application of science calls for clarifying the prerequisites and assumptions made. However, many scientists demonstrate a lack of humility and even their work includes deceit and fraud [149,150]. Another, contrasting critique is that science is not properly contributing to policy. Thus, postnormal science "was designed to apply where facts are uncertain, values are in dispute, stakes high and decisions urgent" [151].

Although the arguments of postmodern science are derived from a philosophy of science perspective and not from discourses or Td processes including different stakeholder groups, it is interesting to see that citizen involvement in the sciences is being promoted. Postnormal sciences suggest citizen science "whereby citizens of varying degrees of scientific literacy take it upon themselves to examine and pronounce on the 'goods' and the 'bads' of science and technology" (p. 21); all quotes in this paragraph refer to [151], and thus it would become something akin to an external public clearinghouse. The authors are promoting "activist-citizen scientists" and "scientist citizens", for "breaking the effective monopoly of peer-reviewed journals" by urging "participation, transparency, and openness" among scientists and between science and practice. It is interesting to see that this "occasionally anarchic" movement is believed to have "high morale and commitment" (p. 24). It is clear that, following this understanding, science becomes only one voice among others. The specific, historically developed differentiation of roles between scientists and practitioners is dissolved. If we change the topic to the arts, one may state that everybody wants to become a ballerina.

The two main pillars of postnormal science, i.e., abandoning the pursuit for realist descriptions and looking for bottom-up citizen processes to validate science, consequently changes the role of science fundamentally. Instead of science as a societal institution that follows processes for approaching more realistic descriptions of the world and that may assist all stakeholders in finding more reasoned and consistent views for following their interests, science becomes one voice among others (see Figure 5).

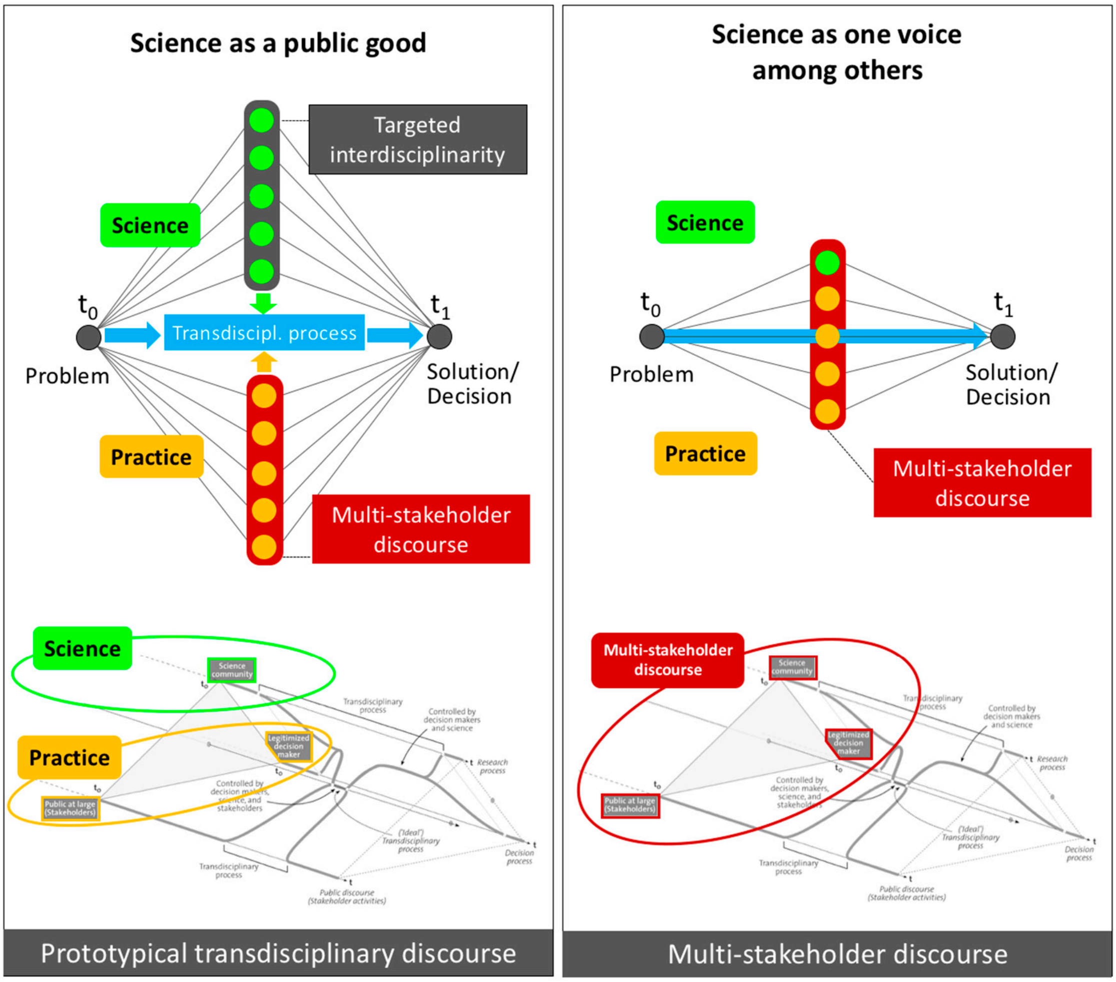

Figure 5. "Science as a public good" that serves all stakeholders (**upper left**) and "Science as one voice among others" (**upper right**) related to the discourse model of Td processes (see Figure 3) in which "Science" and "Legitimized Decision Makers" are included, and scientists induce a Td process including other stakeholders (when taking co-leadership), in turn inducing a process of mutual learning that includes representatives from all relevant stakeholder groups.

4.3. Societal Norms in Science: The Professor as a Stakeholder

Publicly funded institutions such as universities are expected to contribute to social problems such as 'the energy challenge', 'migration management', or 'coping with rebound effects in the digital revolution'. However, how this is done is, in the end, a matter of research, thus, unpredictable, and it has to meet scientific standards. This, unfortunately, is often violated by the practice of fraudulent "courtesy expertise" for politics or industry [152,153] in order to gain a reputation (through sensational results) or money. This is not a new issue [150,154].

Historically, imposing social or religious ideas on science has been an overly delicate issue. Let us briefly look at (just) two examples. We first refer to Kant's last major work, *The Conflict of the Faculties* [155], which was the object of censorship by the Prussian king. Kant's diagnosis was that the science system is dependent on governments' goodwill-dependent financing. He was criticizing the aura of superiority given to theology, law, and medicine by funding and reputation, a result of their strong impacts on and appraisal by societal (utilitarian) interests. He was also criticizing the political censorship of the contributions from the philosophical faculty that was striving toward both a data-based validation and a metaphysical understanding of nature (which today shows up in Mode 1 Td). We can take from this that the "bidirectional impacts" of politics (and social opinions) and science have been an issue since the birth of modern science.

However, professors often function as stakeholders. They switch hats as needed between university professors, industrial leaders, and ministerial advisors [156]. This is common in certain countries and may be seen as a malevolent interpretation of the Triple Helix concept. Naturally, there are no real arguments against this role rotation, given that the separation between roles and functions is properly mastered, but this is not always the case. One of the most evil cases of contamination has been the case of "Aryan physics or physics of the Nordic natured human" [157]. We will look at this in order to better understand and reflect on the limits of citizen science.

After WWI, an increasing number of German professors adopted nationalist, racist ethics [158]. Thus, for instance, there was a vow of allegiance by the professors of German universities and high schools to Adolf Hitler and the National Socialistic State (supported by famous philosophers such as Martin Heidegger and medical researchers such as Ferdinand Sauerbruch), which considered the National Socialist takeover "a complete turnover of our German life" (existence). "Any issue calls for direction and every action responsibility"(The slightly extended German statement reads: "Die nationalsozialistische Revolution ist nicht bloß die Übernahme einer vorhandenen Macht im Staat durch eine andere [...] Partei, sondern diese Revolution bringt die völlige Umwälzung unseres deutschen Daseins. Von nun an fordert jedwedes Ding Entscheidung und alles Tun Verantwortung.") [159]. This clearly also addresses the way that science is conducted. Thus, the Nobel Laureates Phillip Lenard (1862–1947) and Leonhard Stark (1874–1957) linked basic ideas of the Nazi worldview with their judgments of how science should work. "Jewish physics", which was abstract and counterintuitive (e.g., the wave-particular dichotomy) was judged to be "only a paralogism (German Trugbild) and devolution (German: Entartungserscheinung) of the basic Aryan physics [157] (translation of this and other sentences by R. W. Scholz). The situation at that time resembled, at least in some aspects, the current debate on pure, disciplinary research. Based on the message of the vow mentioned above, Deutsche or Aryan physics [157] was abandoning abstract, mathematical Jewish physics, such as Einstein's quantum physics or intuitively paradox phenomena such as the wave-corpuscular theory of light, which did not meet the standard for "common sense" (German: gesunder Menschenverstand). Lenard was promoting a racist, Aryan subjectivism [157] based on principles such as "mechanistic understandability" (p. XX and "Kraft and Energy" (power and energy). The theoretical mind of Werner Heisenberg was attacked as that of a Weisser Jude, white jew; [160] and already tried to publicly defend the weird normative destruction of physics in the central newspaper of the Nazi Regime [161,162].

Lenard and Stark may be viewed as (Nazi-) stakeholder professors. Their example shows how science can become distorted by general folk or religious cosmologies (such as creationism).

Non-science rationales are used to judge 'good' and 'bad' scientific models. Naturally, there are fundamental differences between 'Aryan physics' and 'sustainable physics', but there are also similarities. Mixed societal interests (in warfare or peace, on monism or pluralism, etc.) push, finance, or frame scientific activities. There are more than 150 papers with "sustainable chemistry" in their titles in the web of science. When arguing what this means, for instance, Collins [163] refers to sustainable civilization on Earth as a regulative idea or ethical imperative [164]. Utilizing chemistry or developing chemical knowledge for basing products on renewable resources, substituting oil-based chemical reagents, and chemical processes with low or no pollution are clear operationable goals. However, they are interest-bound, as they refer to a certain prescriptive idea. This is certainly unavoidable and not in itself bad, yet it implies that science is not and has presumably never been an autonomous, self-determining, or objective venture. This aligns with the insight that there is even a social (and thus subjective) nature (of truth) in a mathematical proof [165], as the validation is made by humans. The challenge is to make the normative dimension explicit and to properly reflect on it.

Against this background, this author is perplexed about the suggestion for an unstructured citizen evaluation of 'bad' and 'good' science by citizen panels (sometimes labeled the "democratization of science"). This is rather an absurd and potentially overly dangerous venture.

5. Discussion

5.1. The Transition to a Post-Industrial Society Calls for New Ways of Relating to Science and Practice Knowledge for Complexity Management

The history of science in society shows that the conception, the subject, and the institutionalization of science change with big societal transformations such as the Industrial Revolution. The transition to the 21st century has, thus far, been shaped by tremendous changes including globalization, urbanization, digitalization, increasing distributional injustice, a revival of fierce medieval-like intercultural and interreligious conflicts, the questioning of election-based parliamentarian democracy as a leading form of societal governance, climate change, the loss of biodiversity, and—based on this ensemble of changes—perhaps even a redefinition of humanity and human rights. Thus, it is absolutely and clearly beyond any doubt that the roles, functions, and institutionalization of science are going to change in fundamental ways [166].

The three discussed approaches—Td, TM, and TSc—may thus be seen simply as examples of new ways of doing and utilizing science by redefining the relationship between science and society. Other approaches will develop. There are two main reasons for this. One is the new level of complexity of real-world processes resulting from the major transitions listed above and increased networking. This calls for integrative perspectives, presumably from both a disciplinary inner-science perspective and a societal perspective when the efficient use of segregated science knowledge is desired. Second, in the age of the Anthropocene, human actors become agents in the world system. Thus, no (large-scale) planning or policy can be accomplished without sufficiently incorporating stakeholders. A key challenge here is the capacity to build consensus about what the main challenges are and what processes humankind might employ to cope with them. A prerequisite for avoiding a hard landing is the generation of reflective knowledge about tipping points, environmental and economic rebound effects, etc.

5.2. Transdisciplinarity, Transition Management, and Transformative Science Show Different Types of Ruptures with the Common Science Systems

Against the backdrop of searching for and identifying new ways to conduct and utilize science, two contrary approaches are taken among those discussed. Transdisciplinarity (Td) follows the vision of relating disciplinary, interdisciplinarity, and transdisciplinary processes. Thus, it utilizes the historically organized methods of codifying, transmitting, and developing scientific knowledge that began with the Age of Enlightenment. By contrast, TM considers the current disciplinary organization as obsolete, unreliable (i.e., full of errors and fraud), and, in some respects, dysfunctional. The strategy and aspiration for TM is to proceed with a problem-based approach. This is, in certain respects, similar to Td, which also reverses science's common top-down approach when starting from complex, societally relevant, real-word problems. One major difference is that role and function are assigned to disciplinary knowledge. Another is an overly rapid departure from the historically shaped foundations of the scientific knowledge system, as suggested by the postnormal science perspective.

TM's postnormal science is linked with several cosmological assumptions that we consider very critical, in particular, if we reflect on the roles and functions of science (including social sciences, interdisciplinary, or transdisciplinary science). The worldview of postnormal science eschews the basic aspiration of science to provide a more-realistic description of the real, material, biophysical world. This is recognized when pointing out the tremendous complexity where everything is connected and basic constructs of scientific reasoning such as causality may not be meaningfully applied.

Neither Td nor TSc relinquishes the role and function of specific disciplinary knowledge for sustainable transitioning. Proponents of TSc also acknowledge the clearinghouse function of the disciplines in the infinite discourse of building and validating new theories, conceptions, and constructs for better describing and understanding the phenomena and dynamics of the world system. In the view of this author, TM's skeptical approach with respect to the common science system is linked or even culminates in the vision that citizens' opinions should democratize science. From proponents of citizen science, it has been suggested that citizen boards should evaluate what is good and what is bad science [151]. As we have shown, this is a highly 'populist' venture and reminiscent of the discussed promotion of good, orderly, understandable Aryan physics and the abandoning of bad, inapprehensible, counterintuitive Jewish physics in Germany circa 1930. The democratization of decisions about the (role and funding of) science systems should not be confused with the decision about when science is good, and therefore should be funded, from an inner-science perspective.

Naturally, there are several reasons for taking such a radical perspective and turning completely away from disciplines. One may be the lost belief in a current disciplinary science system that is doubted to be faithful, self-reflexive, free from fraud, and characterized by science-ethos-based research. The other may be a missing epistemological differentiation between knowledge about the potential, limits, complementarity, and relationships between both scientific, rigor-based inferences, on the one hand, and experiential wisdom on the other. Both extremes are forms of epistemics that provide insight into the functioning of the universe, and both have strengths as well as flaws. Which mode is superior depends on the question to be answered and the subsystem of the universe that is considered. We argue that complexity management calls for suitably linking different types of epistemics.

5.3. There Are Different Conceptions of Science as a Change Agent: Facilitation, Catalyst, and Activist

If we pinpoint the differences, one may state that TM is (also) focusing actions on potentially disruptive transitions. Td focuses on capacity building through mutual learning between science and practice, and TSc uses the metaphor of science as a catalyst, i.e., of an "element" that initiates, accelerates, and directs (social) processes in a desired direction. The terms activist (researcher), catalyst, and (reflexive) facilitator illuminate three different roles. One may conclude that the three approaches can be considered different tools from the same toolbox, all designed to better utilize science knowledge for sustainable transitions and able to be applied in different settings (e.g., the Td approach relying on the Habermas deliberative discourse for certain prerequisites). Thus, the three approaches complement each other, such as different forms of action research and other approaches like Translational Research [167].

5.4. There Is a Challenge in Developing a Proper Differentiation Perspective for Complex Transitions

There are two main structures that are dealt with differently by Td, TM, and TSc: the role and function of scientific disciplines and the relationships between science and society. Whereas the Td approach aspires to extend and to restructure the science system along the "disciplined interdisciplinarity on Td discourses" vision (shared by TSc), TM departs from the disciplinary matrix.

Td stresses the specific epistemic and societal functions of science. In contrast, TM widely denies the division between science and practice.

The (formerly hierarchic) disciplinary science system is an invention of the 19th century and is in a process of rapid change and ongoing differentiation. There are more than 12,000 indexed journals in the Thomson Reuters master journal list that can be considered vertebrae in the backbone of science. In addition, there may be a similar magnitude of different master courses, often closely related to specific programs of professional education.

We argue that disciplinary processes of inner science have important functions in the future of human history. These include the structured archiving, efficient codification, and ordering of knowledge, and the quality and clearinghouse function of coherent, consistent theoretical and methodological knowledge, with publications as a component of a filtering process as well as the social organization and evolution of science communities [168,169]. All three approaches agree that society should participate in the process of determining which problems are to be explored and resolved. However, we can easily see the Janus-facedness of "increased levels of advocacy whereby citizens examine the 'goods and the bads' of science" [151]. Td includes stakeholders who take part in all aspects of a Td process and aspire toward co-leadership but also acknowledge the different types of outcomes and reward systems that scientists (e.g., scientific coherence) and practitioners (practical efficacy and efficiency) are facing.

Furthermore, Td promotes the double-peer reviewing of papers, brochures, and books and a differentiation of inputs in the course of a Td process [170] and even develops methods for relating and integrating different types of epistemics [27]. TM and other proponents of postnormal science do not share this position. It appears that the researcher is sometimes changing hats (roles), and the specific properties and functions of science as an abstracted, general reference system of theories and methods becomes completely lost in the process. Thus, the scientist's social values and norms may be at work in an unfiltered way, thereby denying minimum aspects of objectivity and reliability. The professor may act as a stakeholder (see Figures 3 and 5), and the different objectives and reward systems of science and practice may become unimportant [151].

We consider the anti-differentiationist (normal science) perspective (involved in TM) to be highly problematical from a cognitive and philosophy of science perspective. Humans cannot think without differentiation or classification. The postnormal science, TM, and other anti-differentiationist positions, finally "posit atomistic learning and social interaction" [168] when disregarding fundamental insights into the division of cognition [such as intuitive and analytic thinking which differently prevail scientists and practitioner's thinking; [28,122,171] or the division of roles and functions in society, which is natural for any organismic in vivo system [172].

5.5. Normative Issues Are Present in All Domains of Science and Practice

To better cope with the normative dimension, we distinguish between universal and specific norms and social and scientific norms. For human systems, there are 'universal' social norms (such as human rights) and specific social norms (such as personal norms, group norms, local cultural norms, etc.) that are applied by subsystems of the human species. We reveal that, in an era of transitioning to globalization and global digital networking, 'universal' is a relative term. In the science system, we can find general rules (e.g., for earning a PhD) and specific disciplinary rules and norms (each science has its own standards for judging what is a high-quality product). There are ongoing attempts to normalize (and quantify) scientific products (e.g., by science citation indices or by 8000-word papers). However, the diversity of scientific work in the humanities, the arts, and engineering science, for instance, and, in particular, the new forms of interfacial activities of Td, TM, and TSc that generate new types of processes and products (such sociotechnologically robust orientations) do not allow a full normalizing of scientific products. Td is at the crossroads in many respects [137]. There are pressing questions about what is and makes beneficial mutual learning and knowledge integration and how Td processes can be evaluated from a science and societal perspective. This calls for new criteria and rules.

The complementarity between science and society is a construct (such as culture vs. nature) for better understanding certain issues. Science may be conceived as a subsystem or layer of society. The 19th century idea of "freedom of research and teaching" (which is a part of many democratic countries' constitutions) is a normative issue referring to the interface between science and society. Td refers to the science practice of complementarity (see Figure 2) by the idea of co-leadership for materializing egalitarian perspectives. There are double objectives for society (e.g., empowering practice) and science (e.g., redesigning the science system to enable better contributions to sensitive, contested, and complex societal transitions). This is a risky venture that requires new institutional settings, such as protected discourse arenas (Td) or transition platforms (TM). We argue that (ideal) Td processes allow only for sponsorship and not for contract-based projects that often limit science access to data.

New normative dimensions emerge with respect to the intellectual property of ideas, the ownership of sensitive data, or private or cultural secrets. These issues call for detailed contractual agreements. Let us consider two examples. Scientists have to clarify how (new and perhaps not yet finally assessed) data may be handled without losing the freedom of research. Data on contaminated industrial sites or nuclear waste disposals may serve as examples. However, in intercultural Td processes, there are culturally sensitive data that are the property of indigenous peoples, as this author experienced in an intercultural case study of cancer treatment by Guatemalan Mayan healers [173,174]. Scientists and practitioners participating in Td, TM, and TSc processes are facing new types of accountability and responsibility. There is also a need for proper rules and framings to cope with the sometimes-uneven balance of power between science and practice (as well as in non-contract-based ventures).

Many Td, TM, and TSc scientists legitimize their activities when referring to universal norms or agreements such as human rights, UN conventions, or the laws of national conventions such as environmental protections. This is, without a doubt, meaningful, as many universities are public institutions. However, there are ambiguities with historically developing universal norms. For instance, the concept of human rights shaped by Eurocentric norms and values [175] differs from the human concept of "dignity of the human individual" [176,177], and Sharia law is seen as a different rule system "to enlarge freedom, justice, and opportunity for the perfectability of human beings" [178]. This has been neglected and has been identified as the greatest challenge of relating knowledge in Td processes [97]. Although the United Nations is not a supranational institution (but rather only an international organization), the Declaration of Rio or the Paris Agreement on climate change went into effect in 2016 [179] and may be seen as a global norm-like commitment to which science may refer [180].

However, there are also conflictual norms on the level of a nation-state if you think about the topic of waterboarding (which were recently campaigned by US president's Trump) [181], the wearing of burqas (a cultural form of interpreting the Quran's rule of modest dress (Qur'an, Surah 33 (Al-Ahzab), Verse 59), generation II and III nuclear power plants (as a resilient form of energy production), or meat consumption in view of climate change. All these issues may be well dealt with using Td or similar processes. Scientists have their own personal norms and values. A critical and also normative question is how the principle of accepting the otherness of the other, which is seen as a prerequisite for mutual learning [15] and part of Td processes, is interpreted. Here, it is important to explicate the reference scheme of legitimization, interactions, and the roles played by different actors. We think that the chameleon-like change of role functions ("changing hats") is critical, particularly in sensitive, contested issues. According to the author's experience, an activist role is often in conflict with, if not incompatible with, the position of a facilitator or with the idea of science as a public good.

5.6. Inventing New Institutions at the Interface of Science and Society

Since the founding of Bologna University around 1088, the institution of the (Western) university has been in a process of permanent change. The disciplinary-shaped 19th century Humboldtian university introduced disciplines as unit divisions of knowledge, paving the way for communities of specialists [136]. The (German) university followed the functions of teaching (also for professional education, particular for civil service), research, and Allgemeinbildung (general education) in the frame of unity and freedom of teaching and research [182]. The modern system of interacting disciplines with conflicting multi-and interdisciplinary interfaces [183] is an important source for Td that emerged after 1970 in an evolutionary manner (including speciation and extinction) [184]. Thus, the period for the inbreeding of disciplines in disciplinary silos has passed to some extent.

Since the end of the 1980s, it appears that (at least in Central European universities) what have been called 'third mission' or 'third stream' activities have replaced Allgemeinbildung. This is particularly true when we look at the large number of universities of applied sciences that have popped up in many countries. A recent literature review [185] identified a tremendous list of activities such as services to businesses, developing a skilled workforce, spin-offs, knowledge transfer, community service, regional development, participating in policy making, and engaged research that have been subsumed under a third mission in universities. We can see from this list that there has been scant reflection about the functional and institutional differentiations needed to properly serve the broad range of societal demands.

Against this backdrop, we argue that the three different presented approaches do not all call for the same institutional structure. Most, but not all, of the 41 case studies that were conducted by the members of the ITdNet [22] were run involving a large number of researchers from different disciplines, in particular those from urban studies, architecture, different types of engineering, and a wide range of social sciences. The length of the projects (one to five years) met disciplinary needs and started from project-based teaching and the foundation of a Td Lab in 2001. As early as 1993, the organizational chart of the Td case study showed the close connection both to a large scale of scientific institutes and governmental institutions and stakeholder groups [186]. The Td Lab has now become a departmental unit of the Environmental System Science at ETH Zurich.

The TSc approach is currently organized along an interfacial Center for Transformation Research and Sustainability (TransZent) that is formally a joint project of the University of Wuppertal and the (private, see above) Wuppertal Research institute. The lab focuses on real-world labs in Wuppertal and transformation research in North-Rhine Westphalia. The funding is based mostly on national research and community funding. The TM approach started from the idea of problem-based, modeling-focused integrated science, which turned into a transition-oriented institute, DRIFT (Dutch Institute for Transition) in 2004. In the course of commercialization (e.g., by extensive tuitions) of the Dutch universities, DRIFT received a special position that calls for a major amount of external funding. This requires the institute to be highly dependent on external money, e.g., by projects of transition consultancy. Although the institute is related to the sociology institute, it is urged to take an innovative approach and offers "open courses to (a mix of) students, professionals, entrepreneurs, and senior citizens on the theory and practice of sustainability transitions. Our tailor-made offerings include in-company trainings and courses for (local) governments and organizations, thesis supervision for master and PhD students, and research internships" [187]. This may suggest the form of an affiliated institute that is allowed to use the facilities of a university but is funded privately or funded by public research programs, as has been successfully demonstrated by the ISOE institute as a promoter of transdisciplinarity of socio-ecological research for almost 30 years [188,189].

Walking along the road from project initiation to joint problem-definition via co-designing a study, co-construction of knowledge, co-funding, and co-leadership by both science and practice is a rather complex and laborious activity that requires solid, basic long-term funding for scientists. Naturally, teaching and research in the frame of Td, TM, and TSc are in competition with other forms of teaching and research. Scholz and Marks [25] suggested that Td research and processes may be best placed in Td colleges with mid-term projects or even Td universities as suggested by Jantsch [190] that also provide the infrastructure and incentives for people from practice to continuously participate in the governing of a Td study. However, in addition, scientists from different domains may join such institutions for some months or years. Because the link to disciplines is important for Td, a Td college may be well placed as a pivotal institution in or between university faculties.

6. Conclusions

The questions "How should research be done?" (i.e., inner science norms), "What is the science good for?" and "How should science be supported?" (i.e., social norms related to science) are ubiquitous in science. This also holds true for Td, TM, and TSc. All three approaches aspire to utilize science for contributing to the ongoing reflexive transition to a post-industrial, sustainable society by collaborating with stakeholders and policy makers. Thus, there is consistency in regard to societal objectives (i.e., the "good for") and similarity and overlap with respect to many issues.

However, the approaches differ with respect to the question of how research should be conducted. TM is following the tradition of postnormal science and thus departing from some science norms (such as striving for more realistic descriptions of the universe). In contrast, Td maintains the normal approach to science and aspires to extend and alter the science system by transdisciplinary processes. TSc includes many ideas from Td and its methodology and also acknowledges the clearinghouse function of disciplines. TSc aspires to a new governance of science under the perspective of efficient use for local and global societal goals.

There are differences in the roles scientists play in their interaction with practitioners. We have coined these roles facilitator, activist, and catalyst. Td starts from the perspective of science as a public good that should serve all stakeholders and is aspiring to co-leadership in Td processes with a democratically legitimized stakeholder. Scientists contribute to a facilitated theory–practice discourse or play the role of facilitator in developing socially robust orientations. TM is more action oriented and takes a more selective approach, participating in specific activities that meet the scientists (personal) norms of what science should look like in the future. Thus, scientists take an activist role. TSc follows the vision of the scientist as an initiator of and catalyst for sustainable transitioning.

Today's societies are increasingly requesting that universities serve as helpmates (Kofferträger) in order to solve certain problems. The "modern university has become a hybrid institution, with multiple and sometimes incommensurable missions" [98]. We can learn from this paper that new tasks and missions call for new institutional settings. This refers not only to boundary settings but also to inner-university structures and processes that allow us to properly shape and protect inner-science dynamics and the increasing need for an efficient use of scientific knowledge in order to better cope with the challenges of the 21st century. Universities, governmental institutions, industry, and the public at large are challenged to promote institutions at the interface between science and society, which may properly acknowledge and relate the normative dimensions of science and practice.

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