Article

Ways towards Transformation—Conceptual Approaches and Challenges

Leonhard Hennen, Jürgen Kopfmüller, Maria Maia [ID]**, Linda Nierling and Constanze Scherz ***

Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe Institute of Technology (KIT), Karlstr. 11, 76133 Karlsruhe, Germany; leonhard.hennen@gmx.de (L.H.); juergen.kopfmueller@kit.edu (J.K.); maria.maia@kit.edu (M.M.); linda.nierling@kit.edu (L.N.)
* Correspondence: constanze.scherz@kit.edu

Abstract: This Special Issue brings together three fields of problem-oriented research, all addressing the current challenges of our society from different perspectives and respective research traditions, namely: technology assessment (TA), responsible research and innovation (RRI), and sustainability research. In this introductory paper, we point out that these approaches, nevertheless, face similar challenges observing and shaping the current transitions of our society. Conceptual and methodological commonalities and differences in the three approaches comprise issues of normativity in research activities, the interference with democratic decision-making processes, methods and approaches to cope with the expectations of society as well as dealing with the uncertainty and complexity of knowledge. The article closes with a reflection on considerations and decisions of relevance as an overarching challenge for all three concepts.

Keywords: societal transformation; technology assessment; responsible research and innovation; sustainability research; normativity; science in society; policy advice; relevance decisions

1. Introduction: Science for Society and Policymaking—Three Concepts

It is a widespread habit to speak of societal, global or grand "challenges" when referring to the actual and central issues of policymaking and public political discourse. What is beyond idle policy-speak about these terms is that many of the current policy issues, such as climate change, air pollution, soil degradation, pandemics and global justice, as well as the often-militant conflicts related to these problems, are connected to critical views on established modes of production, innovation and lifestyle, as well as a widely felt and articulated demand for "transformation" in this respect.

The term "transformation" then refers to a broad spectrum of established social processes, institutions or systems, political structures and powers, modes of economic production and exchange, as well as culturally embedded patterns of consumption, and attitudes towards nature and ideas of a "good life". The transformations which are envisaged or demanded can be targeted towards single aspects or structures, such as, e.g., a change towards CO_2-neutral modes of e-mobility. But quite often, transformation refers to a fundamental societal change towards a sustainable "livelihood" based on a no-growth economy, with consequences for all dimensions of society and individuals, including capitalist principles of management and investment, and established national and international inequality of distribution of wealth. Incremental governance to successively develop more ecologically and socially sound modes of production and consumption is no longer held to be sufficient in light of the challenges ahead (e.g., [1]).

Thus, the central problems we are facing today appear to ask for innovation. Innovation for societal transformation is not just an issue of introducing new technologies, but is unavoidably a socio-ecological and socio-technical process. It affords reflection on the interplay between social habits and structures, with new technological options through

which reliable knowledge about the efficacy of the envisaged innovation pathways can be generated, as well as possible environmental and other side effects. To provide this type of knowledge, a new approach to research and development (R&D), and first and foremost, a new interaction between science and society is needed. Research has to engage itself in answering normative questions on which ways to go, guided by which value orientations. Research has to interact with extra-scientific types of knowledge, and has to take into account the interests of those who are affected by the demanded transformations and expected to carry the changes ahead. Thus, it is a new type of knowledge that is asked for; knowledge that cannot claim to be "objective" and "disinterested", but has to be relevant for action and helpful for decision-making, that is dependent on reliable data, and informed by an open debate on normative and ethical considerations and problems.

Since the 1960s and the growing insight into the side effects of industrialism and the illusionary character of a technocratic approach to problem solving, awareness of these new challenges for research has been growing. This applies not only to academic science and technology studies working on unravelling the "seamless web of science and society" [2,3], but also, more relevant for this paper, to those working on the practical approaches of research for decision-making. Concepts like technology assessment (TA), sustainability research (SR), and more recently, responsible research and innovation (RRI), which are the focus of this Special Issue, are cases of "post-normal science"; science that is aware of its societal role and the specific epistemological problems that are connected with this role.

We would like to generically coin this type of research as "science for societal transformation". This clearly borrows from the terms "transformation research" or "transformative research", which are used to denote a specific action and change orientation of the type of research that is needed to support the societal transformation towards sustainability, as discussed in many publications for more than ten years now ([4,5], references in [1,6,7]). We hold that the new "transformation"-oriented type of research is not restricted to the normative-loaded concept of sustainable development, as it is, e.g., elaborated in the UN Sustainable Development Goals [8]. Research which provides knowledge for transformative socio-political action is a feature of research for society as an outcome of socio-political changes since the 1960s. These have brought about policy-oriented research strands, that can—using another term—be understood as hybrid science: research that is committed to scientific standards of research as well as to dealing with the problems, interests and perspectives of society that are part of its typical research subjects. The most prominent concepts and fields of research in this respect, besides sustainability research (SR), are TA and RRI. All three share a set of fundamental features and problems that characterize hybrid science, and are connected with changing societal expectations regarding the role of research in transformation processes:

- All three concepts are driven by and address central problems of economic growth, globalization, urbanization or digitalization (such as environmental degradation, climate change, resource scarcity, poverty, extreme inequalities of opportunities to live a decent life), and contribute to the challenging processes of socio-ecological and socio-technical transformation that are needed to tackle these problems.
- Consequently, their research questions and subjects are not of a purely academic nature, but are determined by problems of societal development, defined and debated (in an often-conflictual manner) by societal actors, and usually addressed towards problem-solving for policymaking.
- This implies that research is not only regarded as being accountable towards society but moreover has a societal and public mission, and is in one way or another deeply entangled in public policy discourses and processes of (often institutionalized) policy advice.
- Research for societal transformation unavoidably has to be organized in an inter- and transdisciplinary way. Research typically involves the co-operation of a multitude of scientific disciplines and the co-production of knowledge by scientific and societal

actors alike, implying shared responsibilities for problem definition and research evaluation beyond the borders of the "republic of science".

- Anticipation of the possible effects of options for problem-solving, and reflection on socio-technical futures, is a key feature of problem-oriented research, and apart from new methodological approaches, it demands reflection on the uncertainty and normative ambiguity of knowledge produced and processed during problem-solving.

- Research that aims at anticipating the possible impacts of research and technology, supporting socio-technical transformation and including the views of society, has to be reflexive with regard to its own societal role, its normative foundations, its ethics and politics, and also the potential and limitations of the methods and tools it applies.

The idea of the Special Issue "Technology Assessment, Responsible Research and Innovation, Sustainability Research: Conceptual Demands and Methodological Approaches for Societal Transformations" is to highlight the ways these issues are articulated in the three concepts of TA, SR and RRI, and how they work out in their research practice. We think that in this respect there are differences as well as commonalities to be found that have so far not been sufficiently discussed in the respective scientific communities and thus hamper co-operation. To give one example—it is a common feature of the three concepts to search for innovative means of co-creating knowledge between science and society by involving citizens and stakeholders in the research process. Through this process, all three concepts are confronted with questions regarding the status and reliability of the knowledge addressed, the representativeness and authenticity of the knowledge input of the civil actors involved, and the consequence of the legitimacy and social robustness of the solutions offered to decision-makers. With regard to these and other problems that ask for conceptual and methodological innovation, we would like to prepare the ground for fruitful discussions on possible mutual learning, ways to benefit from one another, and ways to reach reflexive co-operation based on sophisticated approaches to the division of tasks in research. These efforts are needed in order to support transformation processes in the best possible way, and to provide for a legitimate role and convincing performance of research as a partner within these processes.

Following the invitation from the journal "*Sustainability*" to prepare a Special Issue discussing the commonalities and differences between TA, SR and RRI, as well as possibilities of enhancing or combining them, we decided to use this as an opportunity for fostering self-reflection within our own institute, the Institute for Technology Assessment and Systems Analysis at the Karlsruhe Institute of Technology (ITAS). ITAS has experience in the field of policy-related research for government ministries and parliament over more than 40 years. Starting from systems analysis and TA, over the decades, ITAS has engaged itself in the field of SR with conceptual as well as empirical research, and finally also in many projects dedicated to the concept of RRI. In addition to research practice on the societal implications of new technologies, and technology-related policy problems (energy, information and communication, biotechnology, environmental pollution, etc.), ITAS has always been engaged in international debates on epistemological and methodological questions related to the different types of research for societal transformation, without, however, going deeply into a comparison of the three concepts which make up the ITAS' research profile. Thus, this Special Issue was a welcome opportunity to do something about this desideratum and induce self-reflection within the institute about this issue. This explains why the contributions to the Special Issue are mainly written by members of the ITAS staff. The process of producing this Special Issue has served to trigger discussions within our institute that too often fall prey to the demands of everyday projects. Nevertheless, since the beginning, our intention to publish this Special Issue was twofold: to initiate and support self-reflection in ITAS, and to share the insights with a broader audience, in order to contribute to current debates on the complex interrelations between science, policy and society. We hope that these insights promote broader awareness, reflection and discussion about this topic in the international community involved in research for societal transformation. Raising awareness of the problems, limitations and strengths of the three concepts,

making ourselves aware of possibilities to combine concepts and benefit from synergies, and in the long-term induce thinking about necessary reactions regarding methodological innovation and institutional change in the face of social transformations—this is what we hold to be necessary next steps in transformation research, and this is what we hope will be supportive for our colleagues in the international research communities.

In the following parts of the paper, we first introduce and define the term "research for societal transformation" and discuss the particular characteristics and role of TA, SR and RRI in this context (Section 2). We then discuss commonalities and differences between the concepts, pointing to four key challenges they usually face, namely the normativity issue, the relation to policymaking, societal expectations, and complexity and uncertainty issues (Section 3). Based on this, we conclude by identifying and discussing an overarching topic that helps to better understand and address these challenges: relevance considerations and decisions in different conceptual, analytical and procedural respects (Section 4). We finally emphasize that suitably defining, justifying and applying the according relevance criteria is a key precondition for a further improved application of the three concepts.

At the end of this introduction, we want to contextualize and justify our approach in this paper: we focus on a certain type of research, namely transformation-related research. However, we want to emphasize that other types or categories of research do exist which do not explicitly address, or claim to address, topics relevant to transformation processes, but are also highly relevant for transformation and societal development in general. The broad range of basic research or different departmental research settings are to be mentioned here most notably. We do not want to give the impression that only transformation-related research is valid research. Nevertheless, it is essential.

We also emphasize the relevance of inter- and transdisciplinarity and also research modes striving for political relevance, i.e., considering the needs of politicians, as key elements of transformation-related research. But we are aware of the high relevance of disciplinary or multi-disciplinary research modes as a complement to inter- and trans disciplinarity. And we are aware that science always needs to keep the right balance between political relevance (meeting the needs of policymakers), and scientific relevance (requiring a certain distance from policymaking). We point to this as a key argument in the concluding chapter, including the need for suitable criteria for both types of relevance.

2. Research for Societal Transformation

The term "transformation research" is closely connected with the discussion on sustainable development. In a report on behalf of the German Government published in 2011, the German Advisory Council on Global Change (WBGU) coined the term "Great transformation" for the envisaged social and economic changes that would be necessary to arrive at a low carbon economy able to overcome the current system of unrestricted exploitation of environmental resources [4]. The WBGU borrowed the term from the economic historian Karl Polanyi's seminal book on the rise of industrialized societies in the 19th century [9]. Polanyi describes the rise of this new societal formation, which took the whole 19th century, as a fundamental reorganization of societal structures and interactions based on non-regulated markets, which involved a rupture from traditional social structures and a historically unprecedented independence of economy from societal or cultural restrictions and boundaries. Likewise, the WBGU argued that the transformation needed today would involve a new "global social contract" [10] (p. 2), encompassing new modes of production and consumption, as well as modes and structures of decision-making which imply turning away from the fundaments of the transformation to industrialism and unregulated market economy analyzed by Karl Polanyi.

Among the social innovations suggested by the WBGU to realize the great transformation is a prominent new mode of (and role for) scientific research.

> "Transformation research is aimed at understanding transformation processes better, its subject are therefore transformation processes as such. Transformative research supports transformation processes in practical terms through the devel-

opment of solutions and technical as well as social innovations, including economic and social diffusion processes and the possibility of their acceleration, and demands, at least in part, a systemic perspective and inter- and cross-disciplinary methods, including stakeholder participation." [4] (p. 322).

Research would have to be steered towards analyzing the conditions of fundamental transition processes in society (e.g., the interplay between technological innovations and accompanying social and cultural change) in order to draw conclusions for transformations towards sustainability. But beyond this more descriptive "transformation research", there is a demand for strong investment into what the WBGU called "transformative research". This type of research would develop technical as well as social innovations needed for the transformation, as well as the necessary knowledge about critical conditions and the possible impacts of their implementation. Not only would a constant interchange between the two modes of research for transformation—which would have to cross-disciplinary boundaries—be needed, but also a constant exchange of research with society, the economy and politics. This may result in constellations where science and researchers are part of societal transformation processes.

We hold that both the descriptive–analytical and normative–practical aspects involved in science for societal transformation in research practice are connected, and not separate from each other. And we hold that the practical–political turn of research that is addressed in "transformation" or "transformative" research characterizes not only research practices guided by the concept of sustainable development, but applies to a more generic type of policy- and problem-oriented research. This type of research not only aims to contribute to societal problem-solving but is also directly involved in the processes of societal learning and debate, as well as political opinion-forming and decision-making. For this type of research, we use the term "research for societal transformation".

Although this type of "research for societal transformation" clearly has to deal with normative questions, there is no widely accepted definition of "transformation", nor are there clear and widely shared concepts of how, and to what final normative end, transformation is occurring. In SR, beyond general definitions of sustainability goals (such as UN SDGs), there is no consensus how to achieve these particular goals. There is no consensus about the drivers of the main challenges, the nature and scope of the transformation needed, the relevant actors and activities that have to be involved, or the objectives of transformation. On the contrary, these issues are subject to socio-political debates and, thus, also subjects of research in the search for ways out of the status quo. Transformation refers to a shared feeling that we are locked into a path-dependent course (manifested by technologies, markets, user behavior, power relations, political systems, etc.) that is leading to a crisis of resources, environment, societal integration or political legitimacy. Generally, transformation is connected with a perceived need for more reflexivity with regard to the societal effects of "technological progress", including ethical questions of justice and the common good. This crisis is also socially articulated through notions of the inappropriateness of policies and technologies with regard to the central problems of society, or even humanity. This is connected to demands for societal debate on appropriate ways of developing technology, and ways of the deliberative and inclusive steering or governance of socio-technical development.

Transformations that are at issue in particular include projects of "research for societal transformation" that are often incremental and aimed at restricted fields of economic and/or everyday life activities. Others deal with fundamental changes in socio-economic structures and culture, as addressed by the term "great transformation". For the purpose of this Special Issue, we do not need to discuss or decide upon the scope and depth of transformation needed. We simply observe that a broad range of research has been emerging that understands itself as supporting societal practices of problem-solving regarding intricate socio-economical and socio-ecological problems. Without necessarily denying the borders between scientific and practical knowledge, this research regards itself as an integral part of societal practice.

Taking a more generic approach to transformation, it becomes obvious that central features of research that are discussed in the context of sustainability research—namely its normative orientation and its transdisciplinary approach—are also characteristics of other research traditions that have evolved since the 1960s and 1970s. It is obvious that the terms "transformation" or "transformation research" are applicable independently from the sustainability discourse to any research approach or project that intends to directly contribute to socio-political problem-solving through interaction with social actors. This is why, alongside research for sustainable development (SR), we highlight, firstly, the concept and practice of TA, that developed from a specific concept of policy advice in the 1970s into a more encompassing practice of facilitating social discourse and decision-making in the field of science and technology policy. Secondly, we highlight the more recent concept of RRI, which has been promoted since the 1990s as a reaction to the growing demand for co-operation between science and society with regard to the ethical challenges connected with advanced "techno-science", such as nanotechnology or synthetic biology. We regard all three concepts as reactions to a crisis of understanding scientific research as an extra-societal form of independent search for objective knowledge, where the scientific community is understood as an independent entity free from societal influences, as captured in Michal Polanyi's (1962) [11] famous (and notorious) eulogy on the "republic of science". This model has been under pressure since the 1960s, when in many respects a societal consensus on the common good, and science as an unquestionable contribution to the common good, dissolved in the light of unintended problems with "scientific progress". The consequence of opening up scientific research towards society, not only in terms of responding to societal questions and demands, but also epistemically by opening up scientific practice towards the co-production of knowledge and "extended peer communities", was articulated in concepts such as "postnormal science" [12] or Mode 2 production of science [13]. Several other concepts have been in use for the last 15–20 years which articulate a new societal role for science and the specific methodological features that go alongside this mission. "Problem oriented" research is a term that has been developed and used at ITAS to describe central features of research in the context of TA studies [14]. The problems addressed are defined not only scientifically, but are also given definition by socio-political issues and discourses, and research has to contribute to problem-solving by providing knowledge with practical and political relevance. In the US, "action research" has a long tradition at universities, defining a type of research in which scientists directly cooperate with communities or social groups to jointly develop scientific knowledge that is able to contribute to their problem-related activities and fosters the problem-solving capacities of these communities or groups (see, e.g., [15,16]). "Transition research" [17] is another term which has been used to describe the characteristic features of scientific contributions to the transformation of society and the economy towards sustainability by analyzing and inducing targeted innovation processes. Nowadays, concepts of transdisciplinary research describe a form of cooperation between several scientific disciplines on problems that are not only "interdisciplinary" but transdisciplinary, in the sense of being practical or political, and involving non-scientific actors in defining research questions and contributing with their practical knowledge to the research process [18–20]. This is due to and connected with a trans-scientific objective or task of the related type of research. Transdisciplinary research includes the mission to induce transformative change, and combines scientific and societal practice: "Societal effects are a fundamental aim of transdisciplinarity." (p. 243) [18].

In the following sub-sections, we provide a brief account of the three concepts which build the focus of the present Special Issue, as they are integral to the discussion on the tasks and role of science in society, as well as of the developing practice of action- and policy-oriented research.

2.1. Technology Assessment

Technology Assessment (TA) (for an overview see [21]) as a means of policy advice in matters of science and technology (S&T) policymaking has been introduced in many

Western industrialized countries since the 1970s. The concept was developed against the background of the increasing politicization of S&T issues in the 1960s and 1970s, and was originally intended to provide policymaking with knowledge to help steer S&T in a direction which avoided negative unintended impacts and related societal conflicts and legitimization problems for policymaking. Thus, TA has been involved in a scientific policy advisory role in most of the debates on the societal and environmental effects of S&T since the 1960s, involving issues such as nuclear energy, information technology, genetic engineering, sustainable development, and more recently, nanotechnology, synthetic biology or artificial intelligence. With its scientific origins in systems analysis and planning and forecasting, the field of TA has developed since the 1970s with regard to both conceptual approaches and research methods, and has been cast in diverse forms of institutionalization (in parliaments, governments and academia) [22].

A central and persistent feature connected to the founding idea of TA is its orientation towards practical problems of policymaking, and thus its transdisciplinary research approach [23]. TA has always been tied to two principles that have driven its development [24]. One is oriented towards expert analysis, while the other focuses on public deliberation. Accordingly, two models of TA have been pursued: a policy analysis model and a public deliberation model. The policy analysis model was predominant when the Office of Technology Assessment (OTA) was established by the US Congress in 1972. The policy deliberation impulse was important for the foundation of a series of TA institutes related to national parliaments in the 1980s and 1990s in Europe (https://eptanetwork.org/ (accessed on 13 August 2023)). This has been connected with a focus on the involvement of stakeholders and the wider public in TA processes [25–27].

It is evident that TA institutions nowadays differ widely in their advisory practice, ranging from providing scientific advice to policymakers to stimulating public debates and organizing stakeholder and citizen participation in S&T policy (cf. [23,28,29]). Nevertheless, they share—with varying focus and weight—the dedication to scientific policy advice and public deliberation of S&T issues including all affected stakeholders and groups.

Technology assessment must be understood as a reaction to the failure of the "technocratic" concept of the relation between science and politics which was dominant in the 1950s and 1960s and relied on scientific knowledge as a safe and sufficient ground for "rational" policymaking. TA has, thus, always been linked to what has been called a "post positivistic" [30] conceptualization of policymaking, taking into account the inborn uncertainty and underdetermined character of scientific knowledge with regard to complex practical (political) problems, as well as the indispensable need to take into account different (and often conflicting) values, normative claims and expectations held by societal groups: TA has always held to a notion which is currently dominant in most conceptualizations of the relationship between science and politics (see, e.g., [12,31,32]). Transparency of the TA process and openness towards the public, involving a broad scope of interests and values, have been essential features of the TA concept from its inception ([24] (p. 5), [33]). Given TA's link with informing decision-making as a public process, it can be understood as a feature of "Civic Epistemologies", as defined by Sheila Jasanoff (2005) [34].

With its focus on policy advice, TA has a clear mission going beyond pure scientific research. It is meant to inform decision-making regarding salient S&T-related societal problems. In this sense, it is a hybrid concept between science and policymaking, and is involved in processes of transforming social practice through finding answers to salient issues induced by S&T, for which societal consensus on how to react is lacking due to the complexity, normative ambiguities and conflicting social values involved. In TA's self-understanding, the issue of scientific distance or even "neutrality" in political debates has been central, and has recently led to discussions in the TA community regarding neutrality as a myth, which highlights the inherently political character of TA's commitment to public deliberation and inclusion [35,36]. Nevertheless, it is regarded as essential that the political role or character of TA is tied to a commitment to (as far as possible) unbiased scientific research as a basis for providing reliable and socially robust knowledge for social debates

and policymaking. In the latter respect, the awareness of unavoidable uncertainties and ambiguities in scientific knowledge with regard to decisions on societal problems is part of TA's practice, and can be regarded as building on the rationale of its conception. Given the trans-scientific character of the questions TA addresses, besides acknowledgement of the perspectives of stakeholders and social groups, TA has to organize research in a multi- and interdisciplinary way, and remain critical with regard to the inborn uncertainties of disciplinary data and concepts of the complexity and value-laden character of the issues. TA can, thus, be understood as a procedure or framework of organized meta expertise in politico-practical issues [37].

2.2. Sustainability Research

While research on sustainability-related topics has been conducted over several decades, the term "Sustainability Science", including specific objectives, claims and methodological research characteristics [38], has built a basis for an international research community, including study programs, professorial chairs, etc., particularly during the past two decades. It has developed substantially and rapidly, with increasing recognition and relevance in both quantitative and qualitative terms [39]. Its core objectives, as defined by Kates et al. (2001) [40], relate to better understanding of nature–society interactions, identifying sustainable future development pathways, and supporting social learning for the sustainability transformations required. This clearly points to the two basic motivations of sustainability research (SR): to address pressing problems of the Anthropocene, such as climate change, biodiversity loss, hunger, extreme inequalities, etc., and to provide basic orientation for societal development within complex ethical landscapes by informing about preconditions and impacts of different pathways, in order to support societal decisions and decision-makers [41,42].

The most frequently cited origin of the sustainability model, which is the foundation of SR, goes back 300 years to times where many European countries experienced strong dependency on timber wood resources, due to intense mining, ship and house construction, fuel use, etc., and a partly existentially threatening timber scarcity. Facing this challenge, a German forestry guideline ("Sylvicultura Oeconomica") established in 1713 the principle not to cut more wood in a forest in a given period than the forest naturally regrows in this period. This can be seen as an early environmental–economic precautionary principle, in order to simultaneously secure economic activities, daily survival and nature conservation.

In fact, forestry has been the only field of application of this principle for 250 years. And after 200 years of industrialization, urbanization, colonization and increasingly consumption-intensive lifestyles, humankind has experienced substantial progress on a global average regarding income, wealth and eradication of certain diseases, but has also faced a much broader range of global and regional problems: air pollution and resulting diseases, soil degradation, desertification, poverty, hunger, illiteracy, insufficient basic sanitation, energy, etc. In the 1970s, warnings by institutions such as the Club of Rome, pointed to environmental limits to growth, accompanied by a growing awareness of the need to combine issues of environmental protection and societal development. This resulted in the "modern" debate on sustainability in the 1980s, starting with the Brundtland report [43], that defined sustainable development as justice and responsibility within the present and for future generations, basically by securing a decent life and supply of necessary basic goods for every human being. The Convention on Biological Diversity, signed by the international community of states at the Rio Conference 1992 [44] and several subsequent international follow-up conferences and documents, addressed further substantiation and political implementation of the concept.

Today, 300 years after the "Sylvicultura Oeconomica", progress in awareness about and practical implementation of sustainability can be observed in several fields, from urban development to particular technologies such as digitalization. Nevertheless, overall the "world continues on unsustainable pathways" (p. 2) [45]. The design of the United Nations Agenda 2030, with the 17 Sustainable Development Goals (SDGs) at its core, signed by

193 countries, was an urgent and strong reaction [8]. The SDGs currently build the most politically relevant framework, by guiding various national and sub-national sustainability strategies, policies, indicator systems, etc. Criticism has however accompanied this endeavor from the beginning, mainly regarding the non-binding character of the goals and their achievement, and the disregard of power structures, counterproductive drivers, economic growth impacts, extreme wealth accumulation, trade-offs or incompatibilities between goals [46,47].

Nevertheless, the process towards the SDGs and the related political and civil societal efforts towards international agreements prove that sustainable development is a "societal guiding principle" (p. 2) [45], and clearly illustrate its necessarily holistic character. This is expressed by the principle of not only avoiding exceeding ecological planetary boundaries, but also social or social–political boundaries and distortions [48,49], compared to the benchmark of a decent life for everybody. This demands further engagement to accord transformation in all fields of policymaking, including questioning existing institutional structures in policymaking, as well as politics with regard to different actors [1].

Against this background, research and science are increasingly expected to take an essential role in supporting necessary transformations to achieve the SDGs [50–52]. Sustainability science is setting relevant claims [53], by offering to contribute ethical, philosophical and theoretical basics, or theories and concepts of justice [39,41,54], or by addressing issues of measurement, metrics and interdependencies between goals or indicators, in order to support improved designs of political and societal measures [55–57].

Sustainability research is particularly associated with inter- and transdisciplinarity, although these are often accompanied by methodological challenges and controversial understandings of the quality and impact of this type of research [38,58–60]. Although the merits and progress of SR, for instance in understanding natural and social systems and their interlinkages, are appreciated, deficits regarding success in addressing global challenges and solving urgent problems have been stated critically, often by SR scholars themselves. Arguments include the need to improve the capture of the complexity of human–nature relationships, better understanding of the (un)intended impacts of transformation interventions, and better understanding and guidance of socio-technical systems and changes [38,39,42,61].

This is accompanied by demands for the intensification and enhancement of research topics and methods, explicitly and implicitly related to Agenda 2030 and the SDGs, in order to allow sustainability science to better fulfil two key roles: to integrate normative concepts and ideas of sustainability [1], and to scientifically analyze frameworks and conditions for sustainable development, e.g., by integrative research approaches and integrative sustainability assessments [62,63]. In particular, coherence and participation in transformation designs and processes can be mentioned here [57,64–66].

In this context, two thematic and methodological approaches clearly emerge. First, crisis management and prevention, particularly in view of the COVID-19 pandemic, accompanied by strengthening resilience, defined as the ability of systems or institutions to functionally recover from crises. Resilience approaches, being related to risk and vulnerability research, are increasingly emphasized as an element of or complement to sustainability analyses, addressing issues of stability and adaptation, but also transformation and equity [67–71]. The second approach consists of identifying, analyzing and applying leverage points, defined as system elements or attributes where small changes can have strong effects on the whole system [61,72,73]. Based on, among others, system dynamics methods, the objective is to make sustainability policies most effective given constrained resources, e.g., by focusing on "deep" leverage points, such as societal values, institutional designs and dynamics, or sustainability-related learning and knowledge.

To implement these approaches suitably, and particularly to ensure that sustainability science can continue to develop towards an integrative science in terms of appropriately supporting policy and societies in specific sustainability transformation contexts and linking knowledge with action [38], transformations in research processes and the science system

in general will also be necessary, not least as an improved basis for sustainability-related education [74–77].

2.3. Responsible Research and Innovation

Compared to TA and SR, the term responsible research and innovation (RRI) and related conceptual thinking about new modes of research and technology development is a recent development. The first use of the term in Europe and the US, in the context of debates on emerging technologies (nanotechnology, synthetic biology or artificial intelligence), is dated by Brundage and Guston (2019) [78] to mid-2000, but more ambitious conceptual papers on the issue were first published around 2010 [79–81]. A widely accepted generic definition of RRI states:

> *"Responsible research and innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)."* [81] (p. 50)

It is obvious from this definition that RRI shares both objectives and approach with TA and SR. However, its orientation is not towards policymaking, but to organizing the inner workings of research and innovation activities in a responsible and socially inclusive way. In Europe, the mission of RRI to deliver the acceptability, sustainability and societal desirability of innovations was translated into research (funding) practice within the framework of the European Commission's (EC) research program Horizon2020 and has led to the initiation of a broad set of research projects experimenting with new, open and participatory formats, allowing civil society or the interested public to actively take part in the research process. Those involved may be potential users of the innovation at stake, societal groups with an interest in the area of application and/or organized or individual representatives of civil society. This participatory approach is accompanied by including reflection on ethical problems or possible side effects of research as an integral part of research activities, which implies the cooperation of natural and engineering sciences with humanities and social sciences. The EC approach to RRI involved aspects such as gender equality in research practice; open access to scientific data and knowledge; public science education; ethical self-reflexivity in research and innovation; and public engagement in R&D.

While the EC program has been influential in promoting the idea and practice of RRI in Europe, the concept itself developed independently in both the US and Europe. The widely accepted conceptualization of RRI as a framework for research that shows its ambition and criteria can serve the four dimensions presented by Stilgoe et al. (2013) [79]. According to this concept, RRI has to be:

- Inclusive: involve diverse stakeholders (users, NGOs, etc.) in research and innovation (R&I) processes.
- Anticipatory: researchers and innovators are asked to include new perspectives in R&I, agendas for risk assessment, and management.
- Reflexive: researchers and innovators are asked to think about their own ethical assumptions and their roles and responsibilities in public dialogue.
- Responsive: flexibility and capacity to change R&I processes according to public values.
- Beyond the differences in terms of ambition and scope that are identifiable in the various ways of conceptualizing RRI, a common denominator of recent approaches to responsibility is the idea of embedding public accountability in the R&I process itself. This implies not only intense reflection on societal demands and expectations by researchers, but also a tendency to (ultimately) understand R&I processes as the co-production of knowledge with representatives of the public who are embedded in them [82]. Beyond formats of practically integrating societal actors in research (such as in community research, stakeholder involvement, or citizen science), RRI is bound to open up and, in a way, to 'democratize' innovation processes and policies

of R&D. Conflicting norms and values held by society are considered in assessing new technologies and innovations, and the 'black box' of technology development is transformed into a transparent, deliberative process. This applies clearly to RRI 'keys' such as ethics and public engagement, as well as to dimensions such as inclusiveness, reflexivity or responsiveness.

RRI clearly has roots in TA as well as other forms of research on the societal ramifications and impacts of science and technology—such as science and technology studies (STS) or applied ethics such as, for instance, in research on ethical, legal and social impacts of S&T (ELSI research) [83]. It is subject to some discussion to what extent RRI is a continuation or actualization of goals, ideas and approaches that have been tied to TA for decades, particularly to what extent RRI goes beyond the realm and aspirations of TA [84,85]. Looking at the meanings of the term "responsibility" and its use in discussions about responsible science, it becomes clear that the commonalities of both concepts prevail against existing differences [35]. TA was originally regarded as a means to enable politics to steer technology in a socially sound direction, and with the turn to participative methods (e.g., [28]) practically developed its "deliberative" aspects. This strengthened its features as a tool of interactive democratic governance including a broad set of actors. But whereas the focus of TA is on knowledge-based (public) policymaking, RRI aims to embed public accountability in the research and innovation process itself. Whereas TA's deliberative dimension has a focus on public debate, in RRI the involvement of stakeholders is often framed as the co-production of innovations, with representatives of the public embedded in the research and innovation process (laboratories) itself [82]. The latter approach also features prominently in recent developments in public engagement in science promoting concepts such as "user involvement" and "CSO (civil society organizations) involvement" in research and innovation, or "citizen science". This to some extent implies that laypeople in RRI are addressed as users/consumers, whereas in the case of TA they are addressed as citizens.

3. Discussing the Three Concepts

In the following section, we discuss commonalities as well as differences between the three concepts in order to identify opportunities for mutual learning and ways towards productive cooperation. We do this based on the argumentation and findings of the contributions to this Special Issue. When describing the broad scope of experiences and arguments offered in the contributions, we identify four problems or challenges that the three concepts face.

The first is the problem of "How to deal with normativity?". It is obvious that research for societal transformation is engaged in highly normative debates. This applies for the question of envisaged pathways for transformations as well as ethical questions such as those in the debate about synthetic biology, or the question of "How safe is safe enough?" in the case of risk assessment. It is not enough for research to properly discuss these normative problems. Research for societal transformation also has to engage in contested social debates on norms and values of technology, and moreover has to reflect on its own (maybe implicit) normative orientations versus its dedication to scientific independence.

Second, research for societal transformation has to relate and address itself to the processes of democratic decision-making which are necessary to induce transformation programs. Therefore, the question of "How to deal with policymaking?" is unavoidable. How can you effectively organize the interface of research with policymaking? Research has to be politically relevant and has to meet the needs of policymakers in their search for legitimate decisions. This implies again the problem of independence: being politically relevant and at the same time at a distance to policymaking in order to hold to the standards of good scientific practice.

As research for societal transformation is research on behalf of and in the interest of society, it is faced with the question of "How to deal with the expectations of society?". This includes the problem of what are the authentic interests and perspectives of society, and

how can they be properly represented in research processes? Societal problems have to be translated into meaningful and feasible research questions, which involves the problem of the status of scientific vs. non-scientific knowledge, and the role of experts and laypeople. Also, in this respect, there is a problem of scientific independence. Co-production of knowledge also puts the question of the appropriate criteria of quality of knowledge and data to the fore. To what extent can these differ from established scientific standards, and what does this mean for research evaluation criteria such as excellence and research impact?

The subjects of research for societal transformation are not designable according to the ceteris paribus rule, as in laboratory research. The subject comprises the entire complexity of the real world. Research for societal transformation can moreover even be understood as taking part in a real-world experiment. "How to deal with complexity and uncertainty of knowledge?" is therefore a permanent question in order to reflect the practical implications and restrictions of the scientific knowledge involved. Uncertainty is unavoidable, and under-determination of findings with regard to the complexity and normativity of the problem is standard. This is apparent from the necessary anticipatory character of research for societal transformation and its commitment to shaping societal futures. Dealing with uncertainty of knowledge has to be reflected in the research process itself and has to be communicated to society and policymaking to make the preliminary character of findings and the non-mandatory character of solutions clear, and at the same time offer practical perspectives for action.

In the following, the four crosscutting perspectives on TA, SR and RRI will be outlined, bringing central arguments from the contributions to the Special Issue into focus to enrich and fill the perspectives with conceptual ideas as well as empirical evidence.

3.1. How to Deal with Normativity

When reflecting on research for societal transformation, the issue of normativity comes into play immediately when thinking about how to deal with contested values and norms in problem-oriented research. As Görg et al. (p. 2) [1] point out, the debate on transformative research, and of course the contribution of TA, SR and RRI to it, have not only an analytical or political and therefore strategic dimension, but also a normative dimension, pointing to the overarching question: "What is a desirable, fair and feasible future for global societies?". Thus, unfolding normative perspectives and considerations is fundamental to frame and direct strategical and thus political aspects of transformative research.

With regard to the three concepts, the dimension of normativity is taken up differently in each. TA has a central motivation to give policy advice, which should be "neutral and independent". Recently, issues of normativity have been raised here [86]. It was argued that "neutrality in TA is a myth" [87], although it was historically very important for the institutionalization process of TA in the context of policymaking. This marks a contrast to SR or RRI where a normative orientation is in the center of the research (namely Sustainability or responsibility). When addressing the topic of "normativity in TA", questions regarding one's own positioning on values, such as inclusion towards the conceptual frame of a deliberative democracy, are taken up. However, approaches and processes are of importance in order to describe normativity in TA practice.

SR, in turn, is issue-oriented, and takes an active position towards normative questions, such as global justice or environmental concerns. Further, the model ("Leitbild") of sustainability forms an important reference for both TA and RRI research. RRI focuses on innovation practices but takes them in accordance with some basic values, especially the value of responsibility, while also pointing to the importance of stakeholder inclusion for R&I practice.

For all three concepts, finding a balance between the normative orientations of research with reflections on underlying values and inclusive research processes and practices is an overarching challenge. Turning to the contributions of this Special Issue, we discuss first the distinction between the conception and the underlying narrative, second, the

organization of research processes, and third, a case perspective, in order to outline the interdependencies against the background of normativity.

We present reflections on the conceptions and motivations behind the analysis of the difference in the three concepts. Grunwald ([88], this issue) turns back to the second modernity as a reference foil for all three concepts against the theoretical background of the "crisis of modernity". He identifies key commonalities as anticipation, inclusion and engagement, complexity management as well as social epistemology, aiming with different accentuations towards an "intervention rather than limiting themselves to distant observation" (p. 9). This intervention, however, requires continuous reflection on the "direction of the transformation process" (p. 10)—opening up spaces for learning and also re-adjustments of strategies and measures, and a sound contextualization of knowledge for all three strategies.

Complementing the perspective of constant reflection, Schneider et al. ([89], this issue), as well as Büscher and Ufer ([90], this issue), propose concepts for a normative orientation of transformative research, namely the Green New Deal (GND) as a political concept ([89], this issue), as well as the analytical approach of a radical reduction in human activities ([90], this issue). Schneider et al. ([89], this issue) argue for the strong role of visions debated in public as a "starting point of democratic transformation" (p. 13). They use the example of the GND as a vision to which all three concepts could contribute, in order to plead for stronger public intervention by TA, SR and RRI in a reflexive but yet "more visionary way" (p. 13) towards a "democratic shaping of technological change" (p. 13). In contrast, Büscher and Ufer ([90], this issue) analyze the impact of human activities taking a systemic approach, relating them as a "social system" (p. 3) to environmental problems, such as climate change. They conclude that although new technologies are often proposed as a "problem-solver with respect to [. . .] physical eco-system limits" (p. 10), due to the inherent rebound effects which are "activity-reinforcing" (p. 10), socio-cultural innovations need to be targeted towards constraining human activities for the preservation of the whole system.

With regard to the organization of research processes in R&I practice, the value of the inclusion of different perspectives is taken up in all three concepts, although engagement with society plays a different role in each. Emerging as a normative claim of the orientation of R&I practice, the concept of public participation serves as an important orientation for all three research fields. However, there is a different motivation in each, as Weinberger et al. ([91], this issue) point out. In TA, public participation considers the inclusion of a different set of perspectives as well as a variety of solutions. In SR, its function is to reach aims like climate protection or a change in mobility patterns. For RRI, public participation is a way of reflecting on the different aspects that the concept of responsibility includes for different stakeholder groups.

With regard to a reflexive orientation of this engagement practice, the approach of König et al. ([92], this issue) is most comprehensive, by presenting the concept of a "meta-consensus" (p. 8). This implies the high relevance of concluding a consensus, even if a different set of worldviews exists. Such a "meta-consensus" would even take over an "inclusive disunion" (p. 5) of different viewpoints. Coming to the normative orientation of transformation research, such a "normative meta-consensus" (p. 8) recognizing different sides, reflecting that the values of others are legitimate even if they are not shared by oneself, would be an important achievement for engaging with the public and including their views into research and policymaking ([92], this issue).

Kopfmüller and Walz (forthcoming, this issue) address the topic of organizing research processes by discussing the relevance of societal responsibility, as a means of improving both the quality and the societal impact of research, and, based on this, as a basis for rethinking the currently dominating understanding of research excellence. Parodi et al. ([93], this issue) further develop the concept and methods of real-world labs coming from sustainability transformation in order to also embrace TA and RRI research for real-world solutions using a lab approach. The authors propose the "Reflexive Sustainable Technology Lab (RSTL)" (p. 9) as a synthesis of all three concepts. In such a "RSTL", experiments are

run "in, with, and for society in a framed, transparent, and reversible manner" (p. 10), keeping the possibility of exnovation explicitly as a valid option. Although the authors open the concept out towards TA and RRI, the transformative orientation is exclusively towards the normative goal of sustainability. For now, it remains an open question whether the RSTL is put into practice and tested for a range of socio-technical topics, whether this orientation remains friction-free in the field of TA and RRI, or whether amendments towards the normative orientation of RSTL have to be developed.

Finally, the articles in this Special Issue describe relevant cases for understanding the role of normativity in transformative research. On an organizational level, the most prominent "case" is the German Policy Advice unit on TA based at the German parliament (TAB). TAB serves as an institutional actor of TA. Preparing policy advice, TAB uses the Leitbild of sustainability, the paradigm of a deliberative democracy and also the notions of fundamental rights as the background for recommendations. Further, coming from policy advice, it becomes obvious that norms and values as they are accepted in society are enshrined in laws and regulation and thus give a reference to specific legal frameworks, e.g., disability policy or privacy protection, which are again taken up as normative frames when providing policy advice ([94], this issue).

Next to the organizational case, normative issues can be defined on an individual level. Poznic and Fisher ([95], this issue) develop such a framework for the group of engineers as actors in practice for science technology transitions: moral virtues serve here as a category to understand underlying motivations, such as courage or care, serving as the value orientation for engineers.

The contributions to this Special Issue show that a "normative turn" in science, implying that values, motivations and judgements are made explicit and thus discussable and negotiable, is also a valid topic for TA, SR and RRI. For all three concepts, this turn is essential for generating orientation or target knowledge in co-design processes, complementing systems and action knowledge in a reflexive manner. Here, all levels, concepts and methods, as well as implications for organizational and individual actors, have to be taken into account.

3.2. How to Deal with Policymaking

Research for societal transformation does not take place in an ivory tower with a specific disciplinary orientation. Processes for the transformation of society towards an innovative, sustainable and social polity are dependent on interdisciplinary and transdisciplinary research. But—and this is an important specificity of the three concepts TA, SR and RRI as we understand them—this research is closely intertwined with democratic decision-making processes, albeit in different ways. According to this understanding, research for societal transformation can find its way into political consultation processes or it can also react specifically to political requirements.

TA, SR and RRI must be regarded as reactions of articulations of an ongoing restructuring of the relationships between science, society and policymaking. This background implies a close involvement in policymaking, but with differing roles and structural features. The general implications of this process are discussed in Grunwald's contribution to this Special Issue, by applying the concept of "reflexive modernisation" (p. 2) to the three concepts of research for societal transformation (see [88], this issue). From this perspective, it becomes clear that TA, being dedicated to policy advice on the parliamentary and governmental level, differs from RRI, which has a focus on the research process and thus is connected to particular R&D policymaking aspirations to provide responsible and transparent research practices. SR addresses a broad scope of societal actors, policymakers, business as well as NGOs with a dedicated general normative approach to societal transformation.

For TA coming from a tradition of classic policy consulting, political requirements or demands are implied in the research topics defined by policymaking institutions whose demands they are designed to serve, which is in particular discussed by Kehl et al. ([94], this issue). In the case of RRI, the political link is not so much provided by governmental

needs but by applying and reflecting standards of ethics and inclusiveness in the research process itself. As described above, this mission has been translated into research funding practices, such as Horizon 2020. For all three concepts, it is important to disclose and clarify different ways of thinking (in alternatives) to policymaking and to assess their feasibility and (side-)effects, including opportunities and risks. When assessing new technologies, the transformations they might induce have to be considered: "Policy alternatives come from experts. It is the role of experts in such a system to clarify the implications of their knowledge for action and to provide such implications in the form of policy alternatives to decision makers who can then select among different possible courses of action" [96] (p. 12).

From the perspective of policymaking, the first and foremost contribution of research is to support the legitimacy of decision-making, providing for "social robustness" [31]. This unavoidably asks the question about the proper inclusion of society and thus of participatory processes. In this respect, "How to relate to policymaking" is an issue that is implicitly addressed in several of the contributions to this Special Issue. König et al. ([92], this issue) ask how "co-construction of knowledge" (p. 2) for decision-making in the field of emerging technologies can be organized in an effective, i.e., politically influential manner, when it is apparent that often conflicting basic normative assumptions and demands are held by different stakeholders. Weinberger et al. ([91], this issue) explore the need for and possibility of citizen involvement and citizen science as a means of striving for legitimate decisions in technology design.

To improve the legitimacy and acceptance of political decisions in complex socially defined problem areas, Kopfmüller and Waltz (forthcoming, this issue) argue for better societally "mirrored" (responsible) research processes and results as a precondition for successful transition research, and, thus, successful transitions. This implies the need to rethink core elements of science and research related to defining quality and impact and to designing institutional framework conditions, including a "cultural change" in defining and applying the research excellence model. Parodi et al. ([93], this issue) explore the option of citizens interacting with scientists in settings of in situ research on ways to transform their living environment in order to induce sustainable development and appropriate policies. Societal inclusion in this sense is always a means to connect with policymaking by supporting inclusive research, decision-making and knowledge generation, which is addressed in more detail in the following section on "How to deal with expectations of society".

A key precondition of research for societal transformation to define and manage its relation to policymaking is to understand the political nature of transformation discourses. Schneider et al. ([89], this issue) show how the approach of "vision assessment" (p. 2) can serve as a tool to not only grasp the conflicting claims, demands and expectations of future developments that make up societal discourse on transformation, but also to better understand the changing political environment to which research for societal transformation constantly has to adapt. From the point of view of vision assessment, TA, SR and RRI are actors within science–politics arrangements and the related visions of society and strategic agendas for shaping the future ([89] (p. 4), this issue). By developing visions of the future and assessing their feasibility, the three concepts are part of the ongoing political discourse which they have to analyze in order to connect their own work to social demands in a meaningful way. Analyzing the history and content of the Green New Deal (GND) discourse up to its materialization in the current GND program of the European Union, they show the socio-political implications that fueled the development of GND and the different dimensions of its content, especially with regard to the roles ascribed to science and technology. According to the authors, a technocratic and a social justice vision compete in the GND discourse. These visions will, in one way or another, set the political scene for transformation policies (possibly including new political structures and power relations), including very different expectations to which research into societal transformation has to relate. In any case, Schneider et al. ([89], this issue) see a chance and need for transformative research to take a more active political role in shaping and facilitating visions of the GND.

Problems related to the need for institutional independence combined with closeness to politically defined needs are illustrated by Kehl et al. ([94], this issue) in their analysis of the German Office of Technology Assessment's (TAB) occupation with issues of digitalization in several studies over the last two decades. TAB originally followed a traditional "objective" or "instrumental" model of independent expert advice based on scientifically supported insights. The political background in the case of digitalization is, however, strongly defined by debates about norms and standards (e.g., with regard to privacy issues): "norms and values mentioned are widely accepted in society, often even enshrined in law, and are closely linked to the respective political discourse on digitalization" (p. 6). Being characteristic of research for transformation in general, this implies a challenge to any claim of refraining from value judgements in science, and thus asks for reflection on the mission and self-understanding of an institution dedicated to independent policy consulting. Although Kehl et al. ([94] (p. 10), this issue) "observed a strong orientation in TAB's work towards objectivity and authority of scientific knowledge" (p. 10), they also see—as a reaction to this challenge—an "increasing interest in inclusive forms of assessment that let various stakeholders participate in the knowledge acquisition process" (p. 10), as well as attempts to integrate the analysis of digitalization's potential to induce societal changes with normative issues of sustainability.

Scheer et al. ([97], this issue) in their presentation and discussion of the approach of Integrated Policy Package Assessment (IPPA), touch on the issue of serving the need of policymaking in cases of complex and socially contested problems. Their four-step-process is designed to tackle the classical problem of scientific policy advice of, on the one hand, mirroring the full complexity of the societal problem to be analyzed, and, on the other hand, serving the needs of policymaking with regard to the design of practical and manageable options for action. As an integrated approach, IPPA has substantial ties to TA, SR and RRI. The IPPA's intention is to provide (political) decision-makers with suitable transformation and orientation knowledge. The challenge of integrated multi criteria assessment of impacts, stakeholder evaluation and analysis of governance options for sustainable pathways is dealt with via a four-step process of (1) design, (2) analysis, (3) evaluation, and (4) discourse of a "policy package" (2), which is illustrated by a case study of urban passenger transport. Throughout, it is again the inclusiveness and dialogic or discursiveness of the process (by feedback loops with various stakeholders) that is intended to provide for sufficiently complex as well as manageable and legitimate (i.e., socially acceptable) policies.

With respect to the intention of this article, i.e., reflecting about research in transformation contexts, the question of how innovative a research method is can also be answered by measuring how effectively the interface between research and politics is organized. Research for policymaking can be classified as relevant when the impact becomes visible, and this again seems to be the case when the objects of research and the design of the respective research question are also geared to the needs of those to be advised. Ladikas et al. ([98], this issue) point out that there is still a lack of a common approach to assessing the impacts of interdisciplinary research with a societal and policy focus. Based on a bibliometric analysis (publication metadata from important international publication databases), the authors examine the main research fields of TA, SR and RRI studies, and analyze their strengths and weaknesses as well as conceptual overlaps. One of the results is that "TA's impact dimensions are multivariant, and cover its functions not only as a service providing policy options assessment, but also as a process of instigating public debates, based on analyses of dominant values and the inclusion of a wide array of stakeholder input" (pp. 7–8). Once again, the importance of involving stakeholders is evident. The insights of the authors from TAB show that the knowledge of the need to involve more stakeholders is available, but the implementation—at least in the specific case of advice for the German Bundestag—is still in its infancy. This may also be due to the fact that the "distinction between the roles of scientific experts on the one hand and stakeholders as well as policymakers on the other is becoming increasingly blurry" ([94] (p. 2), this issue). The

only thing that can be stated is that there is a need to improve and standardize the societal impact assessment—also in order to better present the contributions of TA, SR and RRI to policymaking. One can still say that "most researchers are not aware of how to achieve such impact or how to measure its success" ([98] (p. 14), this issue).

3.3. How to Deal with Expectations of Society

When considering how the expectations of society are integrated in scientific knowledge production, in TA, SR and RRI the strategy is to open up the R&I system to society, by engaging citizens and civil society as well as users of technologies. The contributions to this Special Issue explicitly address the challenges implied in practices dedicated to co-production or co-creation of knowledge and innovations. When faced with the need to make a legitimate transfer from knowledge to practical solutions and policy measures, as is crucial for transformation research, it is not only the problem of dissenting normative expectations that has to be dealt with. Questions of the reliability and applicability of findings and causal claims for different real-world contexts can compromise the practical relevance of transformation research. Procedures of evidence-based policymaking are limited in this respect. There is no gold standard solution for this in TA, SR and RRI, nor is more synthesis and mapping of evidence a viable way forward. Increased and inbuilt reflexivity with regard to this problem appears to be the only (albeit restricted) option. Thus, the social and political dimension of transformation research comes to the fore: inclusive deliberation, polycentric governance with differentiated policies for differing contexts, procedures supporting mutual trust and mutual acknowledgment of the legitimacy of differing demands and perspectives of actors involved in co-production, and openness to experimentation and learning are keys that come into perspective and underline the hybrid character of transformation research.

The major intention behind starting such a reflexive process on knowledge production is a real-world reflection on the anticipation of possible impacts of technologies. To anticipate such impacts, the involvement of citizens in research needs to be put into practice. From the identification and conceptualization of R&I technological priorities, to its implementation, or by means of co-creation activities, such as citizen science or user-guided innovation, the involvement of citizens or end-users in the development of new knowledge or innovations is characterized by different levels of participation. In addition, to assure inclusion of societal actors, different approaches and methods have been applied and developed in deliberative or participatory processes, such as workshops, focus groups, public discussions, collaboration in fab-labs or real-world labs (see [91–93,97]—all this issue).

Overall, the responsiveness of R&I processes increases as it is aligned with the needs, expectations and values of society. The inclusion of citizens or other societal actors helps to shape the direction of research ([91], this issue), since new perspectives, new research questions and new challenges can be raised by the citizens that otherwise would not be considered. The contributions of this Special Issue highlight two major challenges to including the expectations of society into research and back. First, societal problems, including the interests and knowledge of societal actors, have to be translated into research questions in order to be responsive to societal needs as well as assuring co-production of knowledge, participation and inclusion in research. Second, to consider the expectations of society and to include society into research appropriately, it is essential to develop and apply suitable criteria for the quality and impact of this type of research.

With regard to responsiveness to societal needs, König et al. [92] and Weinberger et al. [91] (both this issue) point to challenges which are related to the practice of engagement in research. According to König et al., one important criterion to assure the quality of citizen engagement activities with regard to reliability is that a diverse set of participants is included. Dealing with inclusiveness in turn raises high complexity, since it can imply different value orientations and moral perspectives of the individuals, thus leading to dissent instead of consent ([92], this issue). These differences have to be dealt with in co-creation activities, respecting that not all debates will be concluded by a consensus.

Thus, reaching an "inclusive disunion" ([92] (p. 5), this issue) can be an important outcome of citizen engagement processes that would at least increase process transparency.

Weinberger et al. ([91], this issue) address the question of factors sustaining citizen engagement. One of the major obstacles for citizen engagement can be a lack of time or incentives, as well as trust in the research process. The latter is strongly related to the management of expectations as well as transparency about project goals and outcomes during engagement activities ([93], this issue). In particular, "individual affectedness" ([91] (p. 6), this issue) can assure long-term engagement in research projects, since participants will be more motivated to be actively engaged over time, especially if the research has a direct connection to their life.

Engagement activities lead to a new type of knowledge for both researchers and citizens. Nevertheless, it remains a challenge to measure the impact of participatory activities. Often, results of citizen engagement processes are context-related; thus, a generalization and extrapolation of results to other contexts are only possible to a limited extent ([92], this issue). Until today, a systemic impact evaluation of the inclusion of societal expectations in research which goes beyond existing methods and context-specific results, as well as a comprehensive and reliable set of indicators, e.g., measuring the added value of the inclusion of citizen knowledge, is still missing ([91,98], both in this issue). Especially for integrated participatory approaches like real world labs, a key challenge is to develop an indicator system that is able to cover both single experimental impacts, and impacts of the lab as a whole ([93], this issue).

Kopfmüller and Walz (forthcoming, this issue) emphasize that increasingly articulated societal expectations on science to provide knowledge to better cope with urgent problems, have particularly motivated the current debates about better considering societal responsibility in research processes and in the science system. They argue that systematically implementing dedicated responsibility criteria leads to better addressing (changing) expectations and enhanced legitimacy, acceptability and acceptance of research results and their application in political decisions.

3.4. How to Deal with Complexity and Uncertainty of Knowledge

The focus of research for societal transformation is not designable according to the ceteris paribus rule as in laboratory research. The subject comprises the entire complexity of the real world. "How to deal with complexity and uncertainty of knowledge" therefore is a permanent question reflecting the practical implications and restrictions of the scientific knowledge involved. Uncertainty is unavoidable, and under-determination of findings with regard to the complexity and normativity of the problem is the standard. This is apparent from the necessarily anticipatory character of research for societal transformation and its commitment to shaping societal futures. Dealing with uncertainty of knowledge has to be reflected in the research process itself, and has to be communicated to society and policymaking in order to make the preliminary character of findings and the non-mandatory character of solutions clear, while at the same time offering practical perspectives for action. It applies to TA, SR and RRI that they are committed to transdisciplinary research as an answer to the complex nature of transformation research. This implies several dimensions of dealing with complexity. The subject, and also the research question related to that subject of transdisciplinary research, is not developed out of the context of theory and academic research. The problem to be dealt with is of societal origin and character. Hence, the research question as well as the expected outcome in terms of problem-solving cannot ad libitum be cut out of a many-faceted reality and be reduced according to the demands of theory and practical considerations of research practice. The laboratory—so to say—for research on problems such as sustainable energy supply, or economic consequences of implementation of advanced technologies, e.g., biotechnology, or user- and patient-friendly designs of medical technologies, is reality itself. This can often even include experiments on a societal level in terms of options and risks of implementing technologies (see, e.g., [99]). Transformative research always means the collaboration of scientific with affected stake-

holders and citizens, and it cannot assume it can avoid a clear separation of facts and values: normative and ethical considerations as well as politics (articulating the interests of the societal groups involved) are unavoidably part of the research process. Moreover, the problems to be dealt with include taking account of possible future societal or environmental effects of the options for problem-solving. In general, possible wider societal future developments that shape the problem area, as well as societal visions and assessment of such futures, and the related uncertainty and ambiguity of data and knowledge are to be taken account of, including according decisions about the methods to be applied.

Thus, dealing with complexity and uncertainty is a common feature and challenge of TA, SR and RRI that is implied by the societal background of problems that the concepts share, as is convincingly shown by Grunwald ([88], this issue). TA, SR and RRI have their raison d'être in a crisis of the so called "first modernity" (p. 3)—modernity (cut short) based on confidence in reason and, thus, in S&T as a guarantee for social progress in welfare and independence from the imponderabilities of nature. The crisis of this conviction, marked by uncertainty and ambiguity of expert knowledge, incalculable risks and unintended impacts of socio-technical change have introduced the need for "reflexivity" (p. 2) in science and policymaking, and this makes up the fundamental characteristic of concepts of transformation research. This common ground of reflexivity is articulated in all three concepts by commitment to exploring the futures (anticipation), and inclusion of different actors in research. It also comes with a concern for managing complexity and an extended epistemology that acknowledges the relevance of non-scientific knowledge. While taking account of the differences between the three concepts (as regards, e.g., the interface with policymaking or the inclusion of normative questions of transformation), awareness of this common ground can help to improve the contribution of the concepts towards what is needed in terms of societal transformation, which Grunwald denotes as "directed incrementalism" (p. 10): a reflexive process of mutual orientation, scientific knowledge and consensus on goals taken step-by-step without becoming lost in piecemeal engineering.

The anticipatory challenge of complexity embedded in transformation policies is articulated in the need for TA, SR and RRI to understand how research and policies relate to visions of society that are implied in the contested approaches to transformation. Vision assessment is a scientific approach to discuss and assess the different and sometimes conflicting conceptions of desired future developments of society that are an unavoidable part of transformation processes. This is convincingly shown by Schneider et al. ([89], this issue) using the notion of the "Green New Deal" (p. 2) that is currently being discussed by relevant political institutions and actors aiming at a fundamental societal transformation towards sustainability. By exploring how the vision of the GND affects and challenges the practice of transformation research, it becomes clear that transformation research requires understanding of the mediality and performativity of future expectations in socio-political approaches to change, including its technical and scientific aspects. Science contributes to the generation and design of visions as well as being the addressee to support their realization. By this, science—which is obvious for TA, SR and RRI—is part of the politics of the future. The GND is a framework for generating visions as well as research questions, and as such provides a challenge to TA, SR and RRI. Using the vision assessment approach in transformation research to analyze the impact of future imaginations, the attributions of meaning given by visions to technology, and the epistemic and normative assumptions underlying visionary thinking can help to foster the rationality, transparency and democratic quality of transformation discourse.

All three concepts have developed procedures that can be called hybrid, meaning R&D processes that address the complex problems we are faced with when trying to grasp the causes of and possible solutions to societal challenges. The approaches applied and the procedures that are developed or experimented with are hybrid in the sense that they integrate research from a broad set of scientific disciplines (natural, engineering or social sciences), combine research with interventions in societal practice, and implement social or technical innovations aiming at socially defined ends. This kind of intervention typically

implies the co-creation of knowledge involving scientific and non-scientific actors, as well as co-operation in defining, finding and designing innovative practices.

A method or procedure that can be regarded as a prototype for this kind of hybrid activity is Real World Labs (RwLabs) ([93], this issue). RwLabs have been developed in the context of SR and politics, but as Parodi et al. show, they have features that make them amenable to typical issues dealt with in TA or RRI. What characterizes many approaches in transformation research—and is systematically taken account of in the RwLab—is its character as an organized learning process that is not one-sided—from science to practice—but mutual. Researchers and stakeholders as well as citizens are part of a laboratory process designed to catch the complexity of real-world problems. The complexity with which all three concepts are faced, and at the same time the complexity of approaches they apply, are sketched by a list of similar characteristics of the concepts addressed in many of the contributions to this Special Issue, highlighted by Parodi et al. ([93], this issue): 1. scientific approach; 2. normativity and responsibility; 3. supporting practice; 4. participation; 5. reference to the future; 6. learning.

That such a hybrid approach demanded by complexity involves problems that have to be dealt with is addressed in many of the articles in this volume. Scheer et al. ([97], this issue) discuss the challenge and suggest an approach to integrated ways to grasp and condition complexity so that it improves the availability of orientation knowledge for policies. Approaches to complexity which promise to support policymaking have to "package" the design, analysis, evaluation and discourse of policy measures in order to provide for "consideration of real world-complexities, uncertainties, and ambiguities" ([97] (p. 15), this issue).

An obvious but, due to its complexity, rarely addressed question is to what extent is the complex nature of challenges such as climate change amenable to human action? What cultural and systemic restrictions have to be taken into account when exploring necessary changes that include serious readjustments of habits and routines that are deeply inscribed into societal structures and practices? The challenges ahead may be of such a complex nature that fundamental transformation is not amenable to human activity ([91], this issue). In asking this question, we have to take into account the systemic nature of our modern life—including complex and interdependent highly organized supply systems and socio-technical formations, as well as related cultural habits and identities. In a systems theory approach to explore the structures and mechanisms resisting transformational efforts, Büscher and Ufer ([91], this issue) argue that systemic reproduction requires a permanent, irreversible sequence of activities, for the supply of energy to human beings and their habitats, and for the creation and maintenance of the structures of social existence. Thus, the options for reduction in human activities, as, e.g., demanded by strategies to reduce CO_2 footprints, might be restricted, especially when investing too much hope in technological innovation. With a view on the activity-reinforcing effect of creative achievements of technical innovation, technology presents itself as an essential driver of human activities—and, thus, counterproductive as regards decreasing energy consumption. The authors argue for fostering research about options for socio-cultural innovations that are likely, or more likely, to impose constraints on human activities.

Kopfmüller and Walz (forthcoming, this issue) propose to enhance the understanding of the quality of research processes by systematically reflecting responsibility criteria, based on a guideline that provides conceptual and methodological basics, including one criterion addressing how to deal with complexity and uncertainty. Since this leads a priori to an increased complexity of research processes, results and their communicability, as well as the processes of evaluating this, they emphasize the need for more systematic, criteria-based and transparent relevance considerations as one approach to deal with this complexity.

4. An Outlook: Considerations and Decisions of Relevance

The previous section outlined the explicit and implicit commonalities and differences between the three concepts of TA, SR and RRI in addressing and dealing with the four chal-

lenges of normativity, policymaking, societal expectations, and complexity and uncertainty. Finally, we want to emphasize an overarching topic that helps to understand and address these challenges: relevance considerations and decisions.

The term "relevance" marks a classic guideline in research and science, focusing on and discussing criteria of scientific rigor and integrity. In particular, since the emergence of the mode 2 approach, and even more in the context of a plea for mode 3 knowledge production [6,100,101], it implies a broader understanding by including societal relevance issues. Today, science is increasingly expected to contribute practical (problem) solutions in transformation processes. Thereby, societal relevance is associated with both the selection of research topics and questions, and with producing and communicating research results. In this respect, a distinction is made between usefulness in a direct and measurable economic sense (products, patents, revenues, etc.), a more indirect form of social influence by changing the social fabric of society (e.g., research used as an agenda-setting tool by media or political establishments), and, finally, contributions to direct social fabric changes (consummation and implementation of scientific products by public, political or economic actors), as the most rare cases [102]. Each of these categories is closely related to considerations and debates about the quality/excellence and impact of research, suitable approaches and measures to make research more relevant to practice and, ultimately, to better link scientific and societal relevance [102–107].

Moreover, knowledge production in research processes, above all in virtually any SR, requires and includes relevance considerations and decisions along the whole process in various respects [108]: determining research questions in detail; defining temporal or spatial system boundaries; determining types and extents of cause–impact–relations, in order to consider all relevant effects, with leverage point analyses (see above) as an emerging example in transformation and transformative research; necessary knowledge stocks and types, disciplines and expertise to be included; societal actors to be involved and the method for this; the criteria and indicators to be applied; methods and tools to be used in analyses, whether quantitative or qualitative, model-based or non-model-based; the way of presenting and communicating results.

Such relevance decisions have consequences. They affect research results and are, thus, an essential element of knowledge production, requiring, in turn, robust knowledge to be justifiable. They affect, for instance, the spectrum of possible transformation-related developments or measures, which are often uncertain regarding their range and the included risks, due to limited knowledge and changing societal preferences. In such cases, relevance decisions bear risks of misjudgment resulting from under- or overestimations of factors or interrelations, leading to biased results. They can be justified analytically by referring to approved methodological knowledge, empirically by referring to experiential knowledge, or more qualitatively based on assessments, interpretations and estimations. Ultimately, such decisions have to be taken by using both, expert knowledge and estimations, including gut feeling, and conflicts about estimations that have to be dealt with.

This is particularly challenging to address in inter- and transdisciplinary research contexts, where agreements and rules, as a consensual basis for relevance decisions, are lacking compared to disciplinary research. While this challenge is at least recognized, controversially discussed and often pragmatically addressed in certain fields of SR, e.g., in life-cycle-based analyses, few overarching considerations exist on a conceptual and methodological level. Fundamental questions of structuring, implementing and justifying relevance decisions are rarely addressed [108]. This is not least due to the fact that relevance-related details widely depend on the specific contexts of investigations and are related to economic, social, geographic, climatic, technological, political, institutional or cultural aspects. Basically, contextualization steps and according configurations of analyses and analytical tools is increasingly emphasized as a methodological key element in research, particularly in sustainability-related research [62,109,110].

Relevance questions characterized as outlined above, in particular in TA, SR and RRI practice, are closely related to the four key challenges characterizing the three concepts.

With respect to normativity, relevance decisions made transparently and based on suitable criteria can, above all, mitigate or at least reduce controversies resulting from criticism of the normativity of fundamental assumptions in analyses, or their lack of justification. However, analyses such as future studies, definitely presuppose relevance decisions (in this case, for instance, the distinction between more or less important scenario descriptors). Like any relevance decision, they are normative per se and, thus, can also be controversial. It is, therefore, essential to focus on both, raising awareness of the "relevance of relevance decisions" in research, and justifying these decisions.

Policymaking should be based as far as possible on considerations of all relevant context-related elements and aspects, in order to both justify the topic and increase the acceptability of decisions. Therefore, according relevance decisions in research processes that produce results for policy purposes are essential. At the same time, equally essential for science is to keep the right balance between political relevance, by meeting the needs of policymakers, and scientific relevance that requires a certain distance from policymaking.

Moreover, public, civil societal and economic actors increasingly expect that research, and in particular research that aims to support societal transformation processes, sufficiently considers all relevant aspects in the particular context, including societal interests and perspectives, in order to provide the best possible advice. This, again, points to an increasing importance of relevance decisions and, in terms of suitable expectation management, to an accordingly increasing attention to appropriate explanations and justifications of decisions—an essential precondition to ensure sufficient societal acceptance or acceptability of actions that are based on these decisions.

Finally, relevance decisions are both all the more important and difficult in particularly complex "real world" research contexts, like those increasingly addressed by TA, SR and RRI. This is true in particular for transformative research, with science being directly involved in transformation processes. Therefore, they have to be taken under notably uncertain conditions. This points to the need to take decisions carefully based on suitable criteria and justifications, to be transparent about the whole process, and also to ensure that decisions can be updated or revised if, for instance, societal values regarding specific relevance considerations are changing. Relevance decisions taken can help to both explain and work within the area of tension between the necessarily preliminary and non-mandatory character of transformative research findings, and the expectation and claim to provide valid support for action.

Moreover, to suitably meet requirements to address the four challenges, to implement holistic, integrative research approaches, and to carry out necessary contextualization steps, also needs relevance decisions with respect to the provision and allocation of additionally necessary resources (funding, time) required within the research process and, above all, in the science system. These decisions are influenced, among others, by ongoing debates about the appropriate role of research and science in transformation processes, and how to define and implement societal responsibility in the different parts of the science system, as discussed in Kopfmüller and Walz (forthcoming, this issue).

The article by Grunwald ([88], this issue) is the only one in this Special Issue that explicitly addresses the relevance topic in a more epistemological sense. He relates relevance to reflexivity, one of the key terms in his article. Particularly, in the context of dealing with complexity, he emphasizes the importance of enhancing reflection on what is regarded as "relevant" (p. 5) and why, in order to increase transparency of arguments and assumptions and the legitimacy of processes and their results in transformation contexts.

In the other articles, the "relevance" term is used more or less frequently, in a more descriptive, attributive way (relevant topics, debates, knowledge, actors, indicators, methods, institutions, etc.), without explicitly addressing underlying presuppositions and epistemological challenges, and their role for the questions and topics that are addressed. This is no criticism of the articles. But from a research theoretical and epistemological perspective, we argue that for thinking about the conceptual, methodological or impact-related challenges faced by TA, SR and RRRI in the context of research for societal transformations, and about

pathways to better deal with these—which is the core rationale and motivation of this Special Issue—more systematic reflection about relevance decisions represents a promising approach for future research. This definitely applies to:

- Questions about how to influence human activities for societal and systemic transformation and the role of extrinsic and intrinsic motivations ([90], this issue);
- Analyzing contested visions, such as the Green New Deal, and the role TA, SR and RRI could or should play ([89], this issue);
- The role of individual moral or epistemic virtues such as care, aiming at "integrative engineering experts" (p. 2) who are competent in socio-technical research on transformative innovation ([95], this issue);
- Pathways towards an inclusive societal co-construction of emerging technologies and supporting innovation governance approaches ([92], this issue);

Working on the challenges of institutional scientific policy advice in a field of tension between scientific integrity and societal and political relevance, and in times of changing science–policy interfaces, needs to be based on scrutinizing previous definitions and applications of relevance criteria, in order to provide advice that meets changing expectations and framework conditions ([94], this issue). This need also applies to:

- Reflections about criteria to define and ways to implement societal responsibility and relevance of research in these times of change;
- The need to rethink key elements in the science system to better meet societal problem challenges and changing societal expectations;
- Reflections about the value and suitable methods of citizen participation in TA, SR and RRI, and if and how this leads to increased relevance of research findings;
- Reflections about what constitutes "impact" of TA, SR and RRI, and how this could be suitably assessed and, ultimately, improved;

Finally, working on integrated policy package assessment approaches (IPPA) to support transformation policies clearly has to address relevance considerations, at least with respect to decisions about the criteria and assessment methods to be used ([97], this issue);
To conclude, relevance considerations and decisions in research are an inevitable element of research for societal transformation. Carrying this out suitably is both challenging and an essential precondition to better understand and, in particular, to better deal with the four key challenges that TA, SR and RRI are commonly facing: normativity, policymaking, societal expectations, and complexity and uncertainty. Relevance decisions are often taken implicitly, disguising their importance, consciously or unconsciously, and underlying criteria and assumptions. Therefore, raising awareness of the "relevance of relevance decisions" and the willingness of actors involved in the science–society–policy interfaces to reveal purposes, advantages and implications of these decision more explicitly, are keys to better (informed) transformation processes. This has to be complemented by training in the required skills, providing spaces to gain practical experience, and framework conditions in the science system that support all this. We hope that this Special Issue can contribute to making progress along this pathway.

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