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# Research and Scientific Advice in the Second Modernity: Technology Assessment, Responsible Research and Innovation, and Sustainability Research

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**Abstract:** The scientific and technological advance has been a major driving force of modernization for centuries. However, the 20th century was full of indications and diagnoses of a deep crisis of modernity. Currently, debates on limits to growth, pollution, and climate change indicate the serious and threatening lack of sustainability of the so-called ‘first modernity’. This crisis of modernity has motivated scholars to develop concepts of modernizing modernity, with the approach of a ‘reflexive modernization’ to reach a ‘second modernity’ being prominent. In this paper, Technology Assessment (TA), Responsible Research and Innovation (RRI), and Sustainability Research (SR) are regarded as manifestations of this reflexive modernization in the field of problem-oriented and transformative research. The paper aims to (a) unfold the hypothesis regarding TA, RRI, and SR as scientific approaches within reflexive modernization, (b) clarify the respective meaning of ‘reflexive’ in these approaches, (c) identify commonalities as well as differences between the three approaches, and (d) draw conclusions for the relation and further development of TA, RRI, and SR.



**Citation:** Grunwald, A. Research and Scientific Advice in the Second Modernity: Technology Assessment, Responsible Research and Innovation, and Sustainability Research. *Sustainability* **2021**, *13*, 10406. <https://doi.org/10.3390/su131810406>

Academic Editor: Clemens Mader

Received: 3 August 2021

Accepted: 16 September 2021

Published: 18 September 2021

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**Keywords:** modernization; risk society; reflexivity; anticipation; inclusion; responsibility; unintended effects

## 1. Introduction

Technology Assessment (TA), Responsible Research and Innovation (RRI), and Sustainability Research (SR) did not originate in the science system but followed demands expressed in society and the political system. The original idea of TA, exploiting scientific expertise to create prospective knowledge on new technology and provide advice to politics and society [1], was born in the US American Congress [2]. The RRI movement, rooted in huge US American research programs, received major momentum in the research policy of the European Union [3,4]. Sustainability Research emerged after the World Summit on Sustainable Development in Rio de Janeiro 1992, which itself was a consequence of the so-called Brundtland report of the United Nations [5]. Hence, a first observation is that all three research practices respond to both societal demand and political need.

In a seminal paper almost thirty years ago, Silvio Funtowicz and Jerome Ravetz discussed a mode of science for dealing with issues where “facts [are] uncertain, values in dispute, stakes high and decisions urgent” [6]. It has been noted [1] that TA in particular is an expression of this type of research. The characterization given in the quote above obviously supports this diagnosis (e.g., [7] for SR). This classification implies accepting that lack of certainty, contested values, neighborhood to society, and involvement of stakeholders’ interests and relations with policymaking are essential in these fields. This is far removed from scientific autonomy and the comfort of closed systems of scientific reasoning in traditional disciplines. In particular, this type of research needs to transcend the familiar concept of scientific peers in favor of an extended peer community, involving other scientific disciplines as well as social actors, stakeholders, and citizens. Thus, the

second observation of this paper is that TA, RRI, and SR can be regarded as mutual neighbors (or relatives) in the field of post-normal science.

The basic thesis of this paper is that the concept of reflexive modernization [8] offers opportunities to perform more in-depth analyses and comparisons of TA, RRI, and SR, both to improve our understanding of all of them but also to derive pathways for further development. Some general measures and strategies, which are regarded as typical for reflexive modernization, such as the precautionary principle, adaptive governance, transition management, and citizen engagement, are also regarded as important for TA, RRI, and SR, with varying accentuations. As will be shown, ‘enhancing reflexivity’ of human action and decision making by providing specific types of knowledge and orientation for specific targets can be determined as a common cognitive interest (*Erkenntnisinteresse* [9]) of TA, RRI, and SR at a conceptual level of reasoning, albeit with different targets and meanings of reflexivity. This cognitive interest allows, on the one hand, a bridge to a second modernity, and it motivates questions of the respective understanding of reflexivity as well as enhancing it. On the other hand, the framework of reflexive modernization enables a more differentiated view on commonalities and differences among the three approaches.

Against this background, following a brief introduction of the concept of second modernity (Section 2), the objectives addressed in the paper are to: (a) unfold and underpin the hypothesis regarding TA, RRI, and SR as scientific approaches to support and realize reflexive modernization (Section 3), (b) clarify the respective meaning of ‘reflexive’ in these approaches (Section 3), (c) identify commonalities as well as differences between the three approaches against the theoretical background chosen (Section 4), (d) discuss the relation and further development of TA, RRI, and SR (Section 5), and draw conclusions for research needs (Section 6).

## 2. First and Second Modernity

Since the Renaissance, the narrative of modernity has become a dominant pattern of thinking and public communication in the Western world. Philosophers such as David Hume, Francis Bacon, and Immanuel Kant contributed to establishing and disseminating modern thinking. Among modernity’s major manifestations are accelerating scientific, medical, and technological progress, economic growth, increasing welfare, and globalization. For decades, modernity denoted a good, perhaps even bright future shaped by human reasoning and rationality, with science and technology as major driving forces; at least in the Western world, and at least for large groups of society. In many respects, expectations related to modernity replaced some religious ideas and converted them from expectations for a good life after death to a good life here on Earth. Various authors have proposed different characterizations around notions such as enlightenment, individualism, freedom, emancipation, progress, rationality, industrialization, capitalist economy, future-orientation, globalization, secularization, democracy, human rights, nation-state, and so forth [1]. Modernity is:

*... a shorthand term for modern society, or industrial civilization. Portrayed in more detail, it is associated with (1) a certain set of attitudes towards the world, the idea of the world as open to transformation, by human intervention; (2) a complex of economic institutions, especially industrial production and a market economy; (3) a certain range of political institutions, including the nation-state and mass democracy. Largely as a result of these characteristics, modernity is vastly more dynamic than any previous type of social order. It is a society—more technically, a complex of institutions—which, unlike any preceding culture, lives in the future, rather than the past. [10] (p. 94)*

However, the 20th century was full of indications and diagnoses of a deep crisis of modernity. Two devastating world wars with millions of people killed, Nazi and communist dictatorships with widespread terror, and the Holocaust motivated Critical Theory to diagnose a deep-lying dialectic of enlightenment [11]. Hiroshima and Nagasaki, Bhopal, Srebrenica and Aleppo, Chernobyl and Fukushima denote places or events rendering any naïve belief in technology false, for different reasons. The debates on limits to growth,

scarcity of resources, pollution, and climate change indicate a serious and threatening lack of sustainability in many fields of human economy and civilization. Globalizing modernity has been driven by colonialism, the suppression of indigenous people, and the exploitation of resources. Instead of an end of history [12] as the victory of first modernity, we are witnessing its global crisis.

Diverging conclusions can be drawn. Post-modern approaches (e.g., [13]) conceptualize a transformation of modernity into something radically different. Other approaches aim to overcome the crisis of modernity by modernizing modernity, i.e., by developing modernity further instead of abolishing it (e.g., [8,14,15]); the basic idea is that some of the potentials of modernity have not yet been exhausted. Pathways need to be explored regarding how and in what direction current thinking should be transformed into a modernized mode of traditional modernity to lead to a “second modernity” [8]. According to the magnitude of the challenge, this transformation will have to address mindsets, reasoning, institutions, and the organization of society at a deep-lying cultural level, as postulated by the approach of a reflexive modernization to reach second modernity [8].

This diagnosis is based on a wide range of empirical observations in various fields. They concern, e.g., the role of the state losing importance with the rise of transnational forces, women’s equality, the changing role of the traditional family, the increasing flexibility of the labor market, and the decline in the binding capabilities of traditional institutions such as political parties, churches, and workers’ unions. Individualization makes more freedom possible; many people can shift from one social position to another in a more fluid manner [14]. However, freedom, is dialectical in itself because of the accompanying effects of social fragmentation and loss of cohesion. The call for populist leaders in many countries could be a counter-reaction to the contingency gap induced by loss of traditional orientation.

In addition to these general sociological observations, a more specific diagnosis of the promoters of reflexive modernization leads much closer to the fields of TA, RRI, and SR. A major element of second modernity consists of the systematic awareness of unintended side effects and risks of human action and decision making [1], often going hand-in-hand with the very successes of modernity: new human-made risks occur, partially on a global scale, as a by-product of the functioning of technology and the economy [16]. Therefore, ecological modernization, as a response to this crisis, is a crucial part of modernizing modernity.

The awareness of unintended side effects and by-products of modernization is at the core of the concept of a “risk society” [17]. Following Beck, scientific and technological progress transforms hazards (threats coming from nature or fate as regarded in traditional societies) into risks (threats where human intervention is part of the cause/effect chains). Beck argues that the occurrence of those effects is not just an avoidable and accidental consequence of modernity but a necessity. He diagnoses an intrinsic relation between increasing complexity due to ongoing modernization, functional differentiation and technological advance, the increasing ignorance of the effects and consequences of actions and decisions, and the decreasing capability of nation-states to cope with these developments when faced with economic globalization and technological complexity. The current COVID-19 pandemic may be regarded as an illustration of these diagnoses.

Complexity due to societal differentiation, the involvement of many actor groups, and systemic effects in innovation chains and socio-technical systems [18] opens the door to unintended side effects. Simultaneously, it provides challenges for anticipating them and finding adequate response strategies. A major origin of this complexity is the strongly enlarged range of consequences of human decision making, both in space and time but also across groups and issues. Cause–effect chains that transgress borders, long-term effects such as storing high-level nuclear waste or intervening into the human germline, globalized consequences of emissions and waste, e.g., of greenhouse gases or micro-plastics, and the consequences for future generations give an impression of this complexity. Individual responsibility becomes more important but simultaneously increasingly obsolete, because of its thinning among a huge number of actors (who is, e.g., responsible for climate change,

and how can any individual's actions make a difference?). Therefore, innovative systemic and institutional solutions must be explored and implemented. Prominent manifestations of reflexive modernity are the precautionary principle for dealing with uncertainty, reflexive governance for the sustainability transition [19], reflexive loops in transition management of infrastructures [20], increasing demand for citizen engagement in public affairs and in scientific research, and recent debates on degrowth (e.g., [21]).

The conceptual difference between first and second modernity can be illustrated by the case of planning. The so-called "rational comprehensive planning" [22] typical of the first modernity approach presumes the plannability of large areas of society at the macro-level. In the ideal case, this has a guarantee of success, assuming the availability of full and certain knowledge, the existence of social regularities or laws, and the rational behavior of humans and powerful institutions in implementing the plans. In full contrast, the second modernity approach is characterized by non-eliminable uncertainty, adaptive procedures, learning by doing, value conflicts, trade-offs, feedback loops, non-linear thinking, flexibility, monitoring, error-friendliness, and resilience.

The role and understanding of science change in second modernity. Contributions from science and research are urgently requested to meet the grand challenges of modern times, e.g., climate change, sustainable development, demographic change, and urbanization. Taking this request seriously has far-ranging consequences for scientific research [23]. Co-design of the research agenda and co-production of knowledge with stakeholders and citizens is of major significance [24]. The need for other perspectives, from e.g., consumers, indigenous people, stakeholders, and patients in transformative projects has become mandatory in many fields. In contrast to former positivism, scientific research in second modernity has to cope with values, as already postulated in the post-normal science paper mentioned above. In a certain sense, it seems fair to say that more and more areas of science move toward the model of post-normal science in a second modernity ([6], see above), while other areas rightfully remain in the first modernity approach.

### 3. Problem-Oriented Research in the Second Modernity

In this section, the approaches of TA (3.1), RRI (3.2), and SR (3.3) will be considered with respect to reflexive modernization. Each of the three approaches will be introduced briefly, followed by an investigation of the specific meaning of 'reflexive'.

#### 3.1. Technology Assessment

Since the 1960s, adverse effects of scientific and technical innovations have become obvious, and some of them are of dramatic proportions. A deepening experience of technological ambivalence led to the crisis of a naïve techno-optimistic belief in progress. The huge impact of today's technology in the *Anthropocene* [25] and the spreading of many of its consequences across space and time demonstrate that introducing new technology by following a 'trial and error' approach or a 'wait and see' strategy cannot be considered to be responsible [26]. The overall mission of TA is to extend foresight and reflection capabilities for shaping the scientific and technological advance and for making best use of its outcomes. To this end, TA has to assess future socio-technical configurations and the societal meaning assigned to new and partially visionary technology in debates [1]. Regarding the co-evolution of technology and society, TA always takes place in context-specific arenas consisting of different actors, institutional settings, expectations, controversies, interests, values, and positions. Therefore, TA practice separates into empirically very heterogeneous fields: (1) TA as policy advice, e.g., to parliaments and authorities; (2) TA as contribution to public dialogue; and (3) TA as part of technology development at the level of engineering. The in-depth investigation of these fields of TA practice allows for the determination of its underlying common cognitive interest [1] (p. 88) as

*supporting, strengthening and enhancing reflexivity in all epistemic and social fields of reasoning and decision-making on shaping the scientific and technological advance, on*

*the usage of its outcomes and on dealing with the consequences to present and future society.*

However, the notion of reflexivity remains rather abstract at this level. In order to make it more tangible, three conceptual dimensions of enhancing reflexivity have been identified to bridge the gap between TA's cognitive interest, as mentioned above, and the fields of TA practice:

- (1) *Anticipation*: TA creates and assesses prospective knowledge about future consequences of technology in a future society, whether intended or unintended, in various forms providing different types of orientation [27]. Enhancing reflexivity means broadening the range of futures considered and making the underlying assumptions, narratives, convictions, values, etc. explicit in order to strengthen reflected and enlightened reasoning, deliberation and decision making.
- (2) *Inclusion*: TA's mission includes involving the perspectives and values of affected actors and groups on the technology under consideration [27,28]. Inclusion in TA consists of a social process with legitimization-creating properties with an epistemic process, which integrates knowledge from different sources. Enhancing reflexivity with respect to inclusion means broadening the perspectives and pieces of knowledge to be involved, and uncovering possible winner/loser configurations and trade-offs in a transparent manner across perspectives.
- (3) *Complexity*: Enhancing reflexivity on anticipation and inclusion has no in-built stop rule. Therefore, TA must include strategies to prevent complexity overload. Reflection is required on what is regarded as relevant, and why, in the respective context. Enhancing reflexivity over issues of relevance means uncovering the arguments behind propositions of relevance, scrutinizing them, and making them transparent to the actors involved in order to arrive at a legitimate balance between the needs for operability and the wish to enhance reflexivity in anticipation and inclusion.

In this manner, on the one hand, TA enhances reflexivity for opening up alternatives with respect to possible futures as well as including many perspectives in the assessment processes. On the other hand, TA simultaneously takes care to reduce complexity and keep projects operable. Thereby, it contributes to reflexively shaping the co-evolution of technology and society. Hence, TA fits well into reflexive modernization [8].

Research in and on TA has a long-lasting tradition starting in the 1970s. In particular, TA methodology has always been under consideration of various scientific disciplines aiming at its further development, which is motivated by the emergence of qualitatively new technologies, e.g., in the digitalization, but also due to changes in society and at the science/policy interface (cp. the reviews on TA research included in [1]). The dimension of anticipation received high scientific attention since the NEST debates (new and emerging sciences and technologies) in the 2000s [26], motivating also the neighbored STS field (science and technology studies, cp. [29]).

The meaning of reflexivity in the three dimensions mentioned converges in a common root: balancing the tension between the wish to open up more options and alternatives as well as to include more perspectives, on the one hand, and the necessity to reduce complexity for reasons of operability and policy advice (closing down), on the other [30]. While this property of TA is in line with basic ideas of second modernity (see above), it contradicts the traditional scientific approach of looking for the 'one best solution' in the attitude of 'science knows best' [31], e.g., by applying an optimization algorithm to a data-based model for calculating the 'best solution'. Hence, thinking in alternatives and reflecting on alternatives is the appropriate mode of operation for TA. The selection among the set of alternative options assessed under the cognitive interest of enhancing reflexivity is made on behalf of the democratic decision-making procedures, because it may involve social values, ideas of justice, winner/loser-configurations, power distribution etc., which do not allow for calculating an optimum. Thus, the meaning of 'reflexive' in reflexive modernization in TA is to consider and conduct processes of opening up alternatives as

well as of reducing complexity with respect to anticipation and inclusion, aiming to provide epistemologically sound and socially legitimized advice to society and policymakers.

### 3.2. Responsible Research and Innovation (RRI)

While RRI is rooted in huge research programs in the US such as the National Nanotechnology Initiative, it was quickly adopted in European science and research policy in order to trigger a new approach to technology and innovation governance. The initial aim was to establish procedures to achieve the “right impacts” and overcome the paradigm of avoiding risk [3]. RRI developed into a procedural approach, which was characterized as (cp. also [4])

*a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to 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. [32]*

RRI can be regarded as a merger of participatory and procedural elements of Constructive TA [33] and explicit ethical reflection over responsibilities and their distribution [34–36]. In particular, the approach of Corporate Social Responsibility (CSR) of companies, entrepreneurs, and innovators shows considerable overlap with ideas assembled in RRI. While RRI is closely related to TA in many respects, it adds explicitly the ethical dimension. In conceptual respects, four dimensions of RRI have been proposed [37,38], “practicing a more responsible research and innovation requires that processes are: diverse & inclusive (. . . ); anticipative & reflective (. . . ); open & transparent (. . . ) and responsive & adaptive to change (. . . )”.

The first two issues directly refer back to anticipation and inclusion as conceptual dimensions of TA as discussed above, which supports the idea of regarding RRI as an element of reflexive modernization. The fourth RRI property makes this conclusion even stronger by referring to properties, which are frequently used in the literature on second modernity (Section 2). While the core of reflexivity in TA consists of reflecting processes of both opening up and closing down (Section 3.1), reflexivity in RRI shows two further elements and accentuations:

- (1) *Actor level:* Reflexivity applies to responsibilities and their distribution among actors involved in innovation processes. What “responsible” means in a specific context will strongly depend on values, rules, customs, etc. [34]. The assignment of responsibility follows social rules based on ethical, cultural, and legal considerations and customs [16] (p. 173) but also needs dialogue and negotiation to take place in particular social and political configurations. Accordingly, three dimensions of the concept of responsibility have to be observed: the empirical dimension of the social actors involved, the ethical dimension reflecting normative criteria for denoting actions as responsible or not, and the epistemic dimension referring to the knowledge available about the object of responsibility.
- (2) *Process level:* RRI supports second modernity via emphasizing and reflecting the procedural dimension of innovation, i.e., procedures of making innovations, of their spread as well as of the responsibilities involved. TA in large parts is dedicated to addressees in democratic institutions, highlighting its function as policy advice, which is reminiscent of first modernity ideas on representative democracy but enriched by ideas from deliberative democracy. RRI prefers the supporting self-organization of civil society and, in particular, the economy, for arriving at right impacts by proper innovation processes (cp. Section 4).

In spite of the short time of RRI’s existence of about ten years only [4], several RRI projects have been conducted, many of them funded by the European Commission, providing a vast body of research results on approaches and methodologies in various application areas [35]. In particular, high effort was spent to adopt the general RRI concept to specific needs of the industry [39].

Thus, the specific subject of reflexivity and enhancing reflexivity in RRI beyond TA is the roles and responsibilities of actors involved in innovation processes. The reflections on the assignment and distribution of responsibility, on processes of innovation instead of objects, and on the governance of innovation allow the conclusion that RRI addresses primarily the organization of good processes of innovation—i.e., well-reflected ones in the sense mentioned above—following the four principles outlined above.

### 3.3. Sustainability Research (SR)

The *Leitbild* of sustainable development requires restructuring the economy and society to ensure that fulfilling the needs of the current generation does not endanger the needs of future generations [5]. Scientific research is indispensable for supporting the transformation toward sustainable development (reviews on the state of the art of transdisciplinary research on sustainable development can be found at [40]). SR necessarily includes dealing with anticipation and, partially, with long-term future considerations. In order to identify and compare appropriate measures to be taken, the expected impacts have to be modeled and extrapolated to the future. As a result of normative requirements, SR also has to be inclusive and participatory. Similar to the TA case, reflexivity concerns anticipation (e.g., [7,41]) as well as inclusion. The transformative mission of SR implies looking carefully at processes of approaching sustainability, of proper governance models, and of assignment of responsibilities. In this respect, reflexivity on actors and processes of sustainability governance is needed, similar to the RRI case. Therefore, while SR is part of reflexive modernization similar to TA and RRI, and obviously directly responds to ecological modernization as part of second modernity, the issue of reflexivity in this field implies additional features:

- (1) *Cybernetic learning cycles*: Any sustainability policy is confronted with—often highly—uncertain knowledge and provisional assessments (e.g., [7]). It cannot be taken for granted whether and to what extent a political measure, a technological innovation, or a new institutional arrangement will really contribute to sustainable development when actually applied. Therefore, every sustainability policy has to become—in a certain sense—experimental [42] and reflexive [19]. It is crucial to exploit the widest range of opportunities for learning in implementing practical measures, and to avoid irreversible effects and path dependencies as far as possible. To this end, careful monitoring of the factual effects of measures is required, as well as the willingness to modify, further develop, or even replace the previously implemented measures. In this sense, the road to a more sustainable future is incremental [43]), in spite of the magnitude of the challenge. It must allow for learning by empirical evidence during the series of incremental steps against the normative sustainability framework guiding the process. In this reflexive way, monitoring, learning, adaptation of measures to new insights, i.e., forming cybernetic learning cycles, are at the core of sustainability governance [7], and these are also typical elements of second modernity.
- (2) *Meaning of sustainable development*: The *Leitbild* of sustainability does not provide a fixed and operable set of criteria ready for application. Rather, it consists of a discursive framework full of ambivalences and conflicts. While this includes a normative core with the imperatives of responsibility for the future and equity in the present, which serves as an orientating compass, it cannot simply be applied as an axiological frame for assessment and guiding action. For example, the Brundtland definition [5] does not determine *how* to act in a specific context, e.g., to restructure public transport in a region, or to re-organize an industrial production process. Instead, this definition gives rough orientation for determining appropriate assessment criteria and developing action strategies. Thus, while deducing or deriving appropriate actions directly from the sustainability definition is not possible, careful reasoning, deliberation, and negotiation are required. These necessarily involve questions about the specific meaning of sustainable development beyond the orientation provided by the Brundtland definition, in particular, for dealing with trade-offs and determining priorities. Re-

flecting sustainable development meaning also relates to the necessity of learning mentioned above, because practical experience can give rise to modifications of the previously determined substantial understanding of sustainable development in order to better fit the abstract Brundtland principle. Therefore, reflection on the meaning of sustainable development must accompany the governance and management of sustainability strategies.

Therefore, enhancing reflexivity by SR requires an exploitation of learning opportunities over time [41] to their utmost, as well as upholding reflection loops with respect to the substantial meaning of sustainability. Management, e.g., with respect to the so-called ecological management rules of sustainability, is necessary to reach sustainability goals but not sufficient. It has to be complemented by continuous reflection in several respects, which allows subsuming SR to the reflexive modernization approach. Hence, the cognitive interest of SR toward supporting and guiding the sustainability transition is deeply interwoven with reflexivity. Including the reflexivity issues already discussed in TA and RRI, reflexivity in SR means keeping a strong relation with empirical developments, in particular monitoring the consequences of sustainability measures and possible unintended side effects as essential elements of learning cycles.

#### 4. Comparison along Cross-Cutting Issues

The explorations of the meanings of ‘reflexivity’ given above demonstrate the close neighborhood of TA, RRI, and SR in many respects but also show some differences. In this section, the commonalities and differences shall be summarized briefly. It is important to note that this categorization works at the conceptual level only, while huge overlap and fluid borderlines may characterize many of the practical activities in these fields in specific projects. For example, there is no problem with combining TA experience of anticipation with RRI ideas on organizing good processes in an SR project. Hence, the following characterization shall inform a reflected discourse among the approaches at the conceptual level. Key commonalities are:

- (1) *Anticipation*: The necessity of anticipation as well as the necessity of reflexivity on anticipation is common to TA, RRI, and SR. It may address issues such as unintended consequences, desired impacts, transformative effects, and uncertainties involved in different composition and accentuation. Reflexivity on anticipation probably has a stronger tradition in TA and SR compared with RRI, but the overarching necessity for reflection on futures and over time [7,41] holds for all three.
- (2) *Inclusion and engagement*: For different reasons, the involvement in projects of stakeholders, citizens, people affected, etc. is a conviction common to TA, RRI, and SR. Co-design of the research agenda and co-production of knowledge in transdisciplinary research, user integration in innovation processes, and participatory TA (e.g., [44]) follow similar ideas of empowerment and deliberative democracy.
- (3) *Complexity management*: Complexity is an issue in TA, RRI, and SR, concerning the systems to be analyzed, options to be explored, actors to be involved, knowledge to be taken into account, etc. Reflexivity regarding relevance, e.g., to determine system boundaries, is crucial, particularly in TA and SR, e.g., in performing prospective Life Cycle Assessments.
- (4) *Epistemology*: TA, RRI, and SR add to traditional scientific epistemology by involving extra-scientific knowledge and by anticipating futures. Social epistemology provides an adequate theoretical framework for knowledge created under conditions of anticipation and inclusion [1,45]. It treats cognition as result of social interaction and collective achievement, oriented by requirements of cognitive quality and, as far as possible, of scientific evidence.

Different accentuations occur in TA, RRI, and SR with respect to intended outcomes, empirical objects of reflection, the respective main target of reflexivity, issues of meaning, and models of governance. The results of Section 3 are provided in Table 1 in a condensed form.

**Table 1.** Different accentuations of TA, RRI, and SR.

Issue	TA	RRI	SR
Outcome	advice to policymakers and society	social and technical innovation	transformation measures and strategies
Empirical objects to be reflected	socio-technical futures (e.g., along assumed consequences of technology)	processes of innovation governance and roles of actors	socio-ecological and socio-economic systems and their dynamics over time
Main target of reflexivity	opening up and assessing options as well as reducing complexity	responsibilities and their distribution for innovation governance	measures, effects and cybernetic learning loops
Meaning to be clarified	societal meaning of socio-technical futures	meaning of responsibility innovators,	meaning of sustainable development
Governance: primary actors	democratic institutions and the public	companies, managers, citizens	policymakers, industry, consumers

The issue of governance needs some explanation. TA has a strong tradition of providing policy advice to democratic institutions. Its origin is representative democracy in the understanding of first modernity. In spite of TA's extension to a more deliberative understanding of democracy, advice to institutions still plays a major role (e.g., [1]). TA gave and gives emphasis to the political level of technology governance and to issues related to the 'common good', as determined by democratic processes and institutions. While TA has transgressed its traditional bounds of parliaments and government by extending into public dialogue and inclusion, as well as increasingly to engineering, RRI operates at some distance from political institutions on the innovation and public involvement side. RRI primarily addresses shaping innovation for application and in the marketplace by applying 'good values' to innovation processes with reflections on responsibility. Thus, RRI may be interpreted as an approach to filling the "legitimacy vacuum" [46] created by Reagonomics and Thatcherism. These approaches weakened political institutions' ability to determine common interests and the common good in favor of market forces. As a hypothesis, RRI offers the possibility to fill the resulting gap with ethical consideration of values and responsibilities in innovation processes in the marketplace. In this field, SR has to cope with the full complexity of a great transformation. Therefore, it is necessary to consider all opportunities and actors of governance in order to assemble as many contributors to this transformation as possible, at all levels of governance [20].

## 5. Discussion

All three approaches aim at 'making a difference'; at intervention rather than limiting themselves to distant observation—i.e., they aim at transformation at different levels. Regarding the grand challenges mentioned at the top of this paper, their contributions will be different at various stages: different targets, different addressees, different sources of normativity, different governance models etc. (cp. Table 1). While addressing governance models, TA's place is more—but not only—in the area of democratic policymaking and public deliberation. RRI emphasizes the role and responsibility of innovation actors in the economy [39] and in society (e.g., [35]), which are frequently related with CSR, while SR is confronted with the overwhelming complexity of sustainability governance (e.g., [7,19,41]).

The overlapping issues of reflexivity and learning give rise to the consideration of commonalities with respect to transformation beyond the differences mentioned. In opposition to the rational comprehensive planning approach (cf. [22]) typical for first modernity, Lindblom and others developed a more incremental, "muddling through" approach [42,43], allowing for continuous learning and opening up opportunities for flexibility and adaptation. Some of the arguments in favor of this approach are analogous

to those given above, i.e., that neither arriving at good innovation nor working toward sustainable development is possible according to a classical planning approach.

However, “muddling through” approaches involve challenges and even pitfalls. In particular, in cases of long-term transformation, they bear risks of losing direction. Examples are the transformation of large infrastructures, e.g., for energy supply or transportation, the safe disposal of high-level radioactive waste, and, above all, the “grand transformation” [47] toward sustainability. Hence, replacing first modernity approaches with mere “disjointed incrementalism” [22] would endanger reaching the transformative objectives and, instead, getting lost in process. Reflexive modernization, in this respect, needs continuous reflection on the direction of the transformation under consideration. Such “directed incrementalism” [7] allows maintenance of the direction of action and decision without fixing goals in detail or falling back on a traditional planning approach. Permanent reflection on the goals and the means to attain them according to the results of continuous monitoring opens up space for learning during the process, and for re-adjusting measures of transformation according to the lessons learned. This is, on the one hand, in accordance with the characteristics of second modernity: non-eliminable uncertainty, adaptive procedures, learning by doing, value conflicts, trade-offs, feedback loops, non-linear thinking, flexibility, monitoring, error-friendliness and resilience. On the other hand, it includes characteristics of TA, RRI, and SR in all their variety.

Obviously, the analysis presented in this paper remains at the level of conceptual developments, key notions, and theoretical reflection. In this manner, it shall open up the way toward a broader but also deeper consideration of research approaches in the reflexive modernization. More specific and, in particular, case-oriented as well as methodological research is needed for underpinning the conceptual results presented here and to gain more in-depth insights for creating benefit for the future development of TA, RRI, and SR.

## 6. Conclusions

The exploration of the meanings of reflexivity in TA, RRI, and SR has resulted in identifying slightly different accentuations and perspectives within the framework of reflexive modernization. The relations between the four dimensions of RRI [37], the cognitive interest of TA of enhancing reflexivity in the dimensions of anticipation, inclusion, and complexity (Section 3.1), and the necessity for reflexive governance in SR [19] considering also issues of time governance [41] clearly show close mutual neighborhood. In the absence of strict contrapositions, there is no reason to exaggerate the differences or to amplify them in favor of an identity policy for creating separate communities. Instead, the task ahead is to reflect on the different accentuations, missions, and strengths in order to constructively identify the best approaches to meet the overarching challenges of reflexive modernization in the fields of technology, innovation, and above all, sustainable development.

These reflections shall be supported and oriented by further case-oriented and methodological research. Regarding the challenges of the reflexive modernization (Section 2) and the characteristics of the “post-normal science” [6] mentioned at the top of this paper, two directions of further research are of major significance:

- TA, RRI, and SR as well have to cope with the necessity of contextualization in order to be able to come up not only with analytic knowledge but also with knowledge for action, e.g., for problem solving in the respective fields. This necessity leads to the well-known tension with the scientific imperative to achieve transferable and generalizable knowledge. All three research approaches have accumulated knowledge regarding how to deal with this tension. It would be highly valuable to explore opportunities for mutual learning, e.g., at the level of methodology [48].
- While TA has its roots in national governance regimes, according to history [1], and while RRI emerged out of highly industrialized countries, SR had to cope with global and intercultural issues from its very beginning [5]. Further research could explore opportunities for mutual learning in order to support reflexive modernization at the global level and intercultural respect by scientific research, supported and under-

pinned by e.g., comparative country studies. Recent activities toward a global TA [49] could be taken as point of departure.

As a concluding remark, I would like to point to urgent necessities for exploring hidden vulnerabilities of modern societies. The COVID-19 pandemic was an eye-opener for hidden or unseen threats and possibly deep-lying vulnerabilities and dependencies. Research for uncovering them and for exploring strategies of strengthening resilience and allowing sustainability transformations are urgently required—these imply enhancing societal reflexivity. TA, RRI, and SR as well are well-prepared for meeting these needs, in cooperation and with mutual learning.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The author declares no conflict of interest.

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