Enacting anticipatory heuristics: a tentative methodological proposal for steering responsible innovation

Sergio Urueña

Published online: 24 Jan 2023.

Submit your article to this journal ↗

Article views: 1271

View related articles ↗

View Crossmark data ↗

Routledge
Taylor & Francis Group

RESEARCH ARTICLE

• OPEN ACCESS   Check for updates

Enacting anticipatory heuristics: a tentative methodological proposal for steering responsible innovation

Sergio Urueña [a,b]

aDepartment of Philosophy, University of the Basque Country UPV/EHU, Donostia-San Sebastian, Spain; bDepartment of Interdisciplinary Studies of Culture, Centre for Technology and Society, Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT

Over the past decade, various normative frameworks that aim to promote more responsible governance of research and innovation in terms of better aligning with society's demands and expectations have emerged. Among the common aspects of these normative frameworks and proposals is the reliance on foresight and/or anticipation as a key interventive dimension or instrument. The article reviews the main challenges to which anticipation has been explicitly or implicitly directed and the respective methodological approaches that have been associated with them. In doing so, the article diagnoses a fragmentation in the methodological treatment of the different challenges. Against this fragmentation, a multi-foresight methodology is proposed. The proposed methodology not only addresses the fragmentation problem by embracing the different challenges posed to foresight/anticipation for promoting more socio-politically responsible technoscientific and innovation practices, but also aims to minimise the uncritical reification of futures.

Introduction

Multiple recent umbrella frameworks point to the need for anticipation as an operational dimension for promoting more responsible research and innovation. Anticipatory Governance (AG) (Barben et al. 2008; Guston 2014), Responsible Innovation (RI) (Stilgoe, Owen, and Macnaghten 2013), Responsible Research or Innovation (RRI) (European Commission 2013a, 2013b; von Schomberg 2013), or recent developments in Technology Assessment (TA) (Grunwald 2019) are examples of normative approaches that explicitly rely on anticipation as a central – though not the sole – procedural dimension to improve co-production dynamics in science, technology, and innovation (STI).[1]

In contrast to the traditional and historically dominant predictive-based approaches to STI governance, anticipation in these normative models takes on a more reflexive character (Guston 2014). Following the foundational work of today's dominant futures studies perspectives, the future is understood as a non-existent (and therefore

CONTACT Sergio Urueña ✉ sergio.uruena@ehu.eus

unknowable), open and plural space (e.g. de Jouvenel 1967; Bell and Olick 1989). Yet, the idea that the future cannot be known does not prevent representations of the future from being considered as heuristically fruitful resources for learning and enacting reflection in the present (Rip and te Kulve 2008; Selin 2014). Concordant with non-predictivist approaches, anticipation is understood by AG, RRI, RI, and TA scholars as a key enabling procedural principle to align STI processes, outcomes, and purposes with societal interests, values, and expectations throughout the whole co-production phases (European Commission 2013b, 4). Accommodating various conceptual broadenings of responsibility and its forward-looking character (e.g. Jonas 1984; Groves 2007; Adam and Groves 2011), responsibility is here understood as 'taking care of the future towards collective stewardship of science and innovation in the present' (Stilgoe, Owen, and Macnaghten 2013, 1570), and anticipation is one of the tools used to promote the ongoing, early, and socially robust problematisation of the futures that are (not) at stake through STI developments (Rip, Misa, and Schot 1995; Guston and Sarewitz 2002; Dupuy and Grinbaum 2004).

Against this context, the call for anticipation finds its most direct operative factor in the execution of foresight exercises such as sociotechnical or techno-moral scenarios (Barben et al. 2008, 993; Selin 2011; Arnaldi 2018; Withycombe Keeler, Bernstein, and Selin 2019). The reflexive heuristics to promote a better STI governance attributed to foresight can take various forms and be targeted at different research and innovation dimensions and fields of action. For instance, it has been stated that foresight might serve in the management of visions and expectations (Warnke and Heimeriks 2008, 79), to shape more systemic thinking for 'socially-robust risk research' (Stilgoe, Owen, and Macnaghten 2013, 1570), or to foster 'practical wisdom' (Boenink 2013) and 'emancipate' societal actors (Withycombe Keeler, Bernstein, and Selin 2019). These heterogeneous heuristics of foresight only mirror the diversity of epistemologies, schools, and modes of orientation that constitute the plural identity of futures studies (Sardar 2010; Grunwald 2014).

In the development of such heuristics ascribed to foresight, the processes channelled by the methodology are of paramount importance. However, methodological architectures are surprisingly under-explored and under-problematised in AG, RRI, RI, and TA literature. As Lehoux, Miller, and Williams-Jones (2020, 1) diagnoses, 'there is little empirical research examining how in practice prospective public deliberation processes should be organized to inform anticipatory governance'. The questions of which methods can better shape responsibilisation heuristics, how and why, have not been at the forefront. Only recently has some conceptual work emerged on the methodological and operational aspects of anticipation within the academic community (e.g. Arnaldi 2018; Lehoux, Miller, and Williams-Jones 2020; Macnaghten 2021).

This article seeks to advance the problematisation of methods for enacting anticipatory knowledge and capabilities aimed at promoting socio-politically responsible STI activities. To this end, it first explores how anticipation/foresight is theoretically understood in AG, RRI, RI, and TA and what challenges are associated with this dimension. It is shown that anticipation is understood and approached as addressing heterogeneous challenges, each of which requires specific forms of engagement with 'futures' (Section 2). The article then analyses 17 practical anticipatory interventions for AG, RRI, RI, and TA. The focus of the analysis is on the methodological structures of the interventions

and how these open up certain STI issues to problematisation and exclude others. In this context, two main limitations are identified. The first relates to the fragmented ways in which the challenges attributed to anticipation are addressed (which hinders the development of holistic anticipatory heuristics). The second relates to the reification of futures (which prevents a deep problematisation of STI) (Section 3). Finally, given the above diagnosis, a tentative architecture of a multi-foresight process is proposed. This procedural methodology aims to promote a more holistic or integral treatment of the challenges that anticipation addresses and minimise the uncritical reification of futures (Section 4). The article ends with a series of concluding remarks (Section 5).

Anticipation as a heuristic resource to foster more responsible research and innovation: conceptualisations and practical challenges

The last two decades have been particularly fruitful in the emergence of governance frameworks that attempt to move beyond the tendency to formulate *ex-ante* responsibility solely based on expert-based models of the future with a predictive ambition. Normative frameworks such as AG, RRI, RI, and TA are clear examples in this regard. These proposals point to the need to develop more socio-politically robust or radical forms of responsibilisation for the tentative governance of STI (see Kuhlmann, Stegmaier, and Konrad 2019).

Aside from the normative nuances that qualify and distinguish AG, RRI, RI, and TA frameworks, they all share their genealogies and coincide in at least two fundamental aspects. On the one hand, they understand responsibility in terms of opening-up to collective problematisation the potential coevolutionary future pathways that the emergence of the STI in question may shape (including the deliberation around its purposes, processes, and 'positive'/'negative' outcomes) (Stilgoe, Owen, and Macnaghten 2013, 1570; von Schomberg 2014). The (im)plausibility and (un)desirability of STI sociotechnical and techno-moral pathways and their respective socio-political and ethical implications are subject to inclusive deliberation. The development of responsible STI would require the involvement of diverse societal actors, concerns, and expertise throughout the whole development process and from its earliest stages (European Commission 2013a; von Schomberg 2013). Responsible STI entails promoting more socio-politically robust and bottom-up, or 'upstream' ways of shaping sociotechnical worlds through STI (i.e. more transparent and aligned with different actors' interests, values, and expectations). Traditionally silenced or marginalised voices would be facilitated to speak out during the STI co-production and governance practices, thus subverting the current hegemonic, technocratic forms of moral division of labour (Rip 2016).

On the other hand, this notion of responsibility finds operational support in the foresight/anticipation dimension in all these frameworks. Anticipation is one of the operational dimensions that, in symbiosis or mutual reinforcement with the other dimensions of each framework, aims to promote this more socio-politically radical and reflexive notion of responsibility. However, despite this constitutive role given to anticipation, there has not been a robust and systematic conceptualisation of what anticipation entails for these frameworks. As Guston (2013, 110) states, anticipation 'is perhaps the most crucial and problematic dimension to deal with', yet it is also the most under-

explored dimension: 'there is less conceptual development around anticipation, and even poorer intuitions'.

A detailed look at the foundational texts of these frameworks can reveal the different roles attributed to anticipation. Table 1 lists some examples of the diverse engagements with the future that each normative framework establishes in its foundational texts when addressing their corresponding dimension of anticipation/foresight.

Table 1 shows that AG, RRI, RI, and TA offer negative and positive definitions in their approaches to anticipation. On the one hand, their negative definitions of anticipation generally exclude interventive actions informed by predictive approaches to the future. Prediction-based forms of governance (often operating in the register of 'probable futures') are regarded as social mechanisms of reifying futures and preserving the status quo (see Ramírez and Selin 2014; Derbyshire 2017), because of their inability to visualise the contingent, open-ended, and plural character of futures and to enable a problematisation of socio-political or normative questions about STI (Sarewitz, Pielke, and Byerly 2000). On the other hand, the common denominator amongst their positive characterisations of anticipation centres on its functions to develop reflexive heuristics and capabilities. Anticipation is understood as a means for enhancing the reflective capital concerning STI orientation throughout their co-production process and at the early stages of development, before the uncritical closure of sociotechnical co-evolutionary pathways. It is a dimension oriented towards the collective problematisation of sociotechnical futures that we enable through STI. In this way, anticipation is primarily a tool for addressing – which does not mean *solving* – the general challenge posed by the Collingridge dilemma (Collingridge 1980).

However, the facilitation of reflexive heuristics for addressing the Collingridge dilemma can be achieved by focusing on diverse issues. Looking at and synthesising the descriptions and goals of anticipation presented in Table 1, one can see that anticipation aims to deal with the Collingridge dilemma by addressing the following three concrete challenges (see also Urueña 2021):

I   To explore the different impacts, sociotechnical configurations and 'endogenous futures' (Rip and te Kulve 2008) that are emerging or might emerge with the development of a particular innovation or technology. The problematisation of impacts is expected to be as broad as possible, including both so-called 'positive' or 'negative' (von Schomberg 2014), and 'hard' or 'soft' (van der Burg 2009b; Swierstra and te Molder 2012) impacts through tentative processes of sociotechnical integration (Fisher 2019). Plausibility is understood here as a relevant criterion and inferential register to simultaneously delimit speculation and the futures and aspects that should be considered (van der Burg 2009a; Boenink 2013), and to pluralise and complexify the considered alternatives for action (see Ramírez and Selin 2014; Urueña 2019).

II *The comprehensive problematisation (in terms of the concerns considered and the actors involved in the deliberative processes) of the purposes and orientation of STI.* The challenge is to take charge of our agency, limited though it may be, when it comes 'to bending the long arc of technoscience more toward humane ends' (Guston 2014, 234).

Table 1. Anticipation in AG, RRI, RI, and recent approaches to TA. Definitions, objectives, and associated techniques.

Normative framework	Definitions of the framework	Other dimensions assembled with anticipation	Objectives and characteristics of foresight/anticipation	Techniques and activities linked to anticipation
Anticipatory Governance (AG)	AG 'comprises the ability of a variety of lay and expert stakeholders, both individually and through an array of feedback mechanisms, to collectively imagine, critique, and thereby shape the issues presented by emerging technologies before they become reified in particular way' (Barben et al. 2008, 993).	Engagement Socio-technical integration	Non-predictivist (does not strive for certainty, or to reduce complexity). Public engagement exercises aimed at 'to help frame debates about the societal implications of new technologies' (Barben et al. 2008, 986). 'seek to integrate reflection with everyday decision making' (Barben et al. 2008, 986). 'to bridge the cognitive gap between present and future' (Barben et al. 2008, 991).	Future scenarios co-constructed in a large-scale through multiple wiki sites Scenario development or visioning workshops Science fiction prototyping
Responsible Research and Innovation (RRI)	RRI 'allows all societal actors (researchers, citizens, policy makers, business, third sector organisations, etc.) to work together during the whole research and innovation process in order to better align both the process and its outcomes with the values, needs and expectations of European society' (European Commission 2013b, 4)	European Commission – Pillars / Themes: Societal engagement, gender, open access/data, science education, ethics, and governance The European Treaty as normative anchor point	'the use of foresight projects can help us to overcome the often too narrowly conceived problem definition scientists implicitly work with' (von Schomberg 2012, 46) 'technology foresight can reduce the human cost of trial and error and make advantage of a societal learning process of stakeholders and technical innovators. (…) This will ultimately lead to products which are (more) societal robust' (von Schomberg 2012, 52) RRI 'processes need to become more responsive and adaptive to these grand challenges. This implies, among others, the introduction of broader foresight' (von Schomberg 2013, 51)	Technology foresight Impact assessment
Responsible Innovation (RI)	RI 'means taking care of the future through collective stewardship of science and innovation in the present' (Stilgoe, Owen, and Macnaghten 2013, 1570)	Inclusive deliberation Reflexivity Responsiveness * Openness	'Anticipation is here distinguished from prediction in its explicit recognition of the complexities and uncertainties of science and society's co-evolution' (Stilgoe, Owen, and Macnaghten 2013, 1571) 'Anticipation prompts researchers and organisations to ask 'what if …?' questions (…), to consider contingency, what is known, what is likely, what is plausible and what is possible. Anticipation involves systematic	Foresight Scenario development Horizon scanning Vision assessment Socio-literary futures-thinking

(Continued)

Table 1. Continued.

Normative framework	Definitions of the framework	Other dimensions assembled with anticipation	Objectives and characteristics of foresight/anticipation	Techniques and activities linked to anticipation
			thinking aimed at increasing resilience, while revealing new opportunities for innovation and the shaping of agendas for socially-robust risk research' (Stilgoe, Owen, and Macnaghten 2013, 1570) Anticipatory methodologies 'serve as a useful entry point for reflection on the purposes, promises, and possible impacts of innovation' (Owen et al. 2013, 38)	
Technology Assessment (TA) (recent approaches)	'TA is an interdisciplinary field of scientific research and advice, which aims to provide knowledge and orientation for better-informed and well-reflected decisions concerning new technologies and their consequences' (Grunwald 2019, 1–2)	Inclusion Complexity	'*anticipation* addresses the dimension of time when facing an open future: enhancing reflexivity *over time*' (Grunwald 2019, 2) Anticipation aims to stimulate actors to productively imagine options for desirable technological futures (Decker et al. 2017) 'foresight in TA is increasingly oriented towards processes of knowledge co-generation between different actor groups' (Sotoudeh and Gudowsky 2018, 53)	Foresight Scenario development Vision Assessment Hermeneutic Technology Assessment

*Dimensions added by Owen and Pansera (2019).

III *The promotion of critical capacities concerning future representations and ways of using the future that de facto colonise the present of STI governance dynamics (both formal such as predictive regimes of governance, and informal such as governance mechanisms through visions, promises, and expectations).* Who creates and mobilises these futures, what assumptions do they carry, who do/did they mobilise and why, how do they become socially established and socio-politically relevant, who is included or excluded in these futures? (Jasanoff 2020).

The operationalisation of anticipation in recent literature: uses of the future and challenges addressed

Most of the literature on AG, RRI, RI, and TA focuses on the theoretical development and critique of the dimensions represented in each of these frameworks. However, less attention has been paid to problematising their interventive practices. How are the above challenges addressed in the exercises that engage with futures? To what extent are these challenges addressed comprehensively? What methodological structures define foresight exercises?

This section provides an exploratory analysis of 17 sources that depict anticipatory intervention exercises for AG, RRI, RI, and TA. Given the exploratory nature of this analysis, it does not claim to be exhaustive. The analysis is pragmatically oriented to diagnose some tendencies in the operationalisation of anticipation and to highlight some of their weaknesses.

The selection of the resources under analysis was determined by the simultaneous fulfilment of three basic conditions:

(1) The exercise presented should have an evident anticipatory-interventive character. In other words, the resource should showcase a type of exercise that is based on engagement with futures. This requirement excludes research concerned with the theoretical underpinnings of the rationale for this type of interventions.
(2) The operationalisation is explicitly presented as an exercise in the service of supporting AG, RRI, RI, and/or TA. This excluded from the analysis anticipatory interventions coming from other fields, such as Futures Studies.
(3) The resource should be sufficiently detailed in the process being followed to allow for meaningful analysis.

Eight variables were considered during the analysis: the framework(s) of reference (AG, RRI, RI, and/or TA), the specific STI that is the subject of the intervention, the methodology and structure of the exercise, the types of engagement with futures (see below), the participants mentioned, which of the main challenges were addressed (i.e. whether 'I.', 'II.', and/or 'III.'), and the openness and closure dynamics that these exercises facilitate.

These variables are interrelated, especially the challenges addressed and the types of engagement with the future. The types of engagement with the future and their interconnections with the challenges are the following (see also Urueña 2021, 275–276):

- *Exploratory*: Non-predictive representations of futures which allow to draw a series of lessons and reinforce a series of capabilities (e.g. moral imagination).

○ *Evocative*: 'Useful fictions' depicting hypothetical worlds. Some forms of evocative scenarios are sociotechnical scenarios and techno-moral scenarios. While the former evoke potential co-evolutions between STI and society, the latter focus on potential co-evolutions between STI and morality. These exercises are especially linked to the challenge of promoting a more socio-politically robust analysis of STI outcomes (i.e. 'I.').

○ *Normative*: 'Useful fictions' depicting hypothetical worlds that certain subjects consider (un)desirable to pursue. Normative scenarios are usually used to open deliberative spaces to discuss the purposes that certain social agents intend to tackle. These exercises are especially useful for problematising the aims and purposes STI is intended to address (i.e. challenge 'II.').

- *Strategic*: 'Useful fictions' that represent hypothetical milestones and their respective causal chains that might trigger or avoid the futures in question (whether those futures are predetermined or derived through exploratory exercises). These forms of engagement with futures are crucial for the elaboration of practical guidelines that enable action in the face of the outcomes presented in evocative explorations, or that enable action in the face of the futures presented in normative explorations.

- *Critical-hermeneutic*: It aims to deconstruct the futures that colonise the present and usually close-down the frames through which the other ways of engaging with the future mentioned above take place. This kind of engagement with the future is particularly useful in combating the reifying power of futures (i.e. to address the challenge 'III.').

The results presented in Table 2 show the heterogeneity of approaches to anticipation in practice and allow several conclusions to be drawn. Due to space constraints, only the most relevant results are highlighted below. These results will inform the value of the methodological structure of the multi-foresight process described in the following section.

The most relevant and general conclusion that can be drawn from the data presented in Table 2 is the existence of a fragmentation when it comes to addressing the various challenges that anticipation poses (i.e. 'I.', 'II.', and 'III.') – an exception is the *Transformative Vision Assessment* method recently proposed by Schneider et al. (2021). In other words, the data suggest that the anticipatory exercises for AG, RRI, RRI, and TA are not comprehensive enough when it comes to problematising the different dimensions of STIs: their outcomes ('I.'), their purposes and processes ('II.') and their associated narratives, visions, promises, and expectations ('III.'). The analysis thus shows that STI is problematised (promoting dynamics of openness), yet this problematisation is simultaneously typically restricted to different domains of STIs (promoting dynamics of closure).[2]

The analysis shows, for example, that there is a strong tendency to understand anticipation in terms of exploring impacts, be they technical, sociotechnical, or techno-moral. This is reflected in the widespread use of tools such as sociotechnical and techno-moral scenarios in the implementation of anticipation. The challenge that AG, RRI, RI, and TA anticipatory exercises tend to address in practice – considering various gradations of inclusivity, responsivity, and reflexivity – is 'I.'. This can be interpreted in the light of

Table 2. Analysis of interventive anticipatory exercises.

Source	Framework(s) of reference	STI domain of intervention	Methodology & structure	Types of engagements with futures	Participants (as mentioned)	Challenge (s) tackled	Opening aspects	Closure aspects
Rip and te Kulve (2008)	TA	Nanotechnology	*Socio-technical scenarios:* (i) Construction of the scenarios by the organisers; (ii) discussion of the scenarios with enactors (articulate challenges for the commercialisation/application and ELSI); (iii) articulate approaches and way to deal with the identified challenges	Exploratory-evocative Strategic	Enactors Selectors	I	The discussion is intended to move away from technical particulars, with a focus on generating reflexivity through contestation and articulation of participant's 'worlds'	The scenarios are created by the organisers Scenarios are narrowly focused on surpassing the challenges that might hamper the development and commercialisation of nanotechnology: A socio-political critique of the purposes and socio-political projects of nanotechnology is missing
Swierstra, Stemerding, and Boenink (2009)	TA	Obesity Pill	*Techno-moral scenarios:* Explore potential pathways for the co-evolution of the innovation with values, obligations, and responsibilities	Exploratory-evocative	–	I	Introduces the co-evolutionary aspect between technology and morality Use of scenarios as a heuristic resource to facilitate discussion on the 'soft impacts' of techs, and thereby assess their associated ethical and desirability and enhance 'moral imagination' Diversity of viewpoints as an asset	The scenarios are created and discussed by the organisers The focus is on potential controversies and not so much in co-production
Robinson (2009)	TA/RRI	Nanotechnology	*Co-evolutionary scenarios:* (i) Construction of the scenarios by the organisers (capture the complexities of innovation journeys and (co-)evolving environments); (ii) discussion of the scenarios with multi-stakeholders (formulation of strategies and concrete steps to take action)	Exploratory-evocative Strategic	Multi-stakeholder	I	Combine concentric and multi-level approaches through emphasising sociotechnical co-evolutions Problematises current 'endogenous futures' to enable more responsible modulations (emphasis on steps to take action)	The scenarios are created by the organisers The focus on identifying the underlying dynamics of co-evolution for strategy formulation comes at the expense of neglecting the problematisation of the purposes of such strategies
Selin (2011)	AG	Nanotechnology	(i) Development (constructing nano-enabled product scenes	Exploratory-evocative (development and	Social scientists Nanoscientists	I	Opens spaces for discussion and reflexivity	Reifies futures of the innovation: reflections seem to be limited to

(Continued)

Table 2. Continued.

Source	Framework(s) of reference	STI domain of intervention	Methodology & structure	Types of engagements with futures	Participants (as mentioned)	Challenge(s) tackled	Opening aspects	Closure aspects
			with nanoscientists); (ii) vetting (establishing technical plausibility, seeking alternatives); and (iii) deliberation (critique, expansion, and discussion of the scenes by stakeholders)	vetting) Exploratory-normative (deliberation)	Broad range of stakeholders			the functions of the artefacts and their possible impacts (without problematising the goals and underlying visions)
Douglas and Stemerding (2014)	RRI/AG	Synthetic biology	(i) Review reports and articles that highlight potentially promising applications of SynBio; (ii) perform ELSI analysis to these applications; and (iii) negotiate and strengthen the identified ELSI with participants and explore governance approaches to balance benefits and risks	Exploratory-evocative	Policymakers Analysts Regulators Ethics committees Patient organisations Academics (philosophers, social scientists, SynBio researchers) International health organisations Research funders ONGs	I	ELSI questions were kept open in a flexible way to allow for new insights from the participants Involve a wide range of societal actors The organisers acknowledge that the ELSI scenarios did not meet their expectations	Reinforce SynBio's promises related to the selected applications The most important ELSI aspects discussed were identified by the organisers of the intervention The ELSI-SynBio scenarios does not capture the complexity of sociotechnical and techno-moral co-evolutions Reduces responsibility to the 'ethics management' of ELSI concerns
Mann (2015)	TA	Biodiversity offsets and banking	(i) Identify actors and create scenarios ('endogenous futures'); and (ii) debate the scenarios	Exploratory-evocative Exploratory-normative (deliberation on already co-created futures)	Experts Public representatives Environmental NGOs	I II	Opens spaces for discussion and reflexivity about the purposes and problem-frame of biodiversity Shows that controversies are underpinned by different worldviews and philosophical and political orientations	Scenarios are not created by the participants, but are pre-set, which can significantly frame the debate
Sadowski and Guston (2016)	AG	Nanotechnology	(i) Identify actors; and (ii) conduct a questionnaire on the future of nanoscientists' research and potential outcomes	Exploratory-normative	Nanoscientists	I	Provides insight into the opinions of nanoscientists on the future of their work It might generate reflexivity among nanoscientists	There is no collective debate or problematisation on nano
Lucivero (2016)	TA	Immunosignatures Nanopil	*Techno-ethical scenarios*: Explore potential pathways for the co-	Exploratory-evocative	Academics	I		The exploration is limited in terms of (i) actors involved, and (ii) variables

			evolution of the innovation with values, obligations, and responsibilities *Techno-moral vignettes*: Narratives that explore potential ('soft') impacts of techs on forms of life, and morality.				discussion on the 'soft' impacts' of techs, and thereby assess their associated ethical and desirability and enhance 'moral imagination' Raises critical questions about the socio-systemic activities and outcomes that the scenarios may enable	considered (e.g. 'patient-centered' vs. 'doctor-mediated') The discussions are framed by pre-given scenarios
Gudowsky and Sotoudeh (2017)	RRI/TA	Autonomous living of older adults	*Transdisciplinary, visioneering co-creation process*: (i) Citizens produce visions; (ii) experts and stakeholders elicit societal needs based on '(i)' and formulate recommendations for R&D agendas; and (iii) the citizens validate '(ii)' output	Exploratory-normative Strategic	Laypeople Experts Stakeholders	=	Visions have societal issues at their centre: Politics on STI purposes comes first to prevent the problem from being framed in purely technical terms	It assumes an epistemic and moral division of labour among the actors Citizens' visions may be biased by promises, expectations, and previously circulated visions It does not problematise scenarios about the possible consequences of STI and their plausibility and desirability
Bechtold, Capari, and Gudowsky (2017)	TA/RI	Ambient and Assistive Techs (regarding ageing issues)	Scenarios	Exploratory-evocative	Experts Stakeholders Laypersons	I	It displays the common denominators of different publics' perspectives and desires (experts, stakeholders, laypersons) Explorations are focused on how STI will affect different actors, and not so much on the STI itself	It assumes an epistemic and moral division of labour among the actors, and discussions take place in parallel. No scenarios are envisaged where the very existence of the STI at hand can be questioned
Arnaldi (2018)	TA/RRI	Nano neural implant	*Retooled Techno-moral scenarios*: (i) Sketching the landscape (technoscientific, moral and socio-economic); (ii) generating controversies (pros and cons for the creation); and (iii) closure and responsibility regimes (who is responsible, responsibility configurations, means for support responsibility)	Exploratory-evocative (pros and cons) Strategic (who should be responsible, under which means to support certain responsibility regimes)	Publics, experts, stakeholders	I	Introduces explicit reflection on who should be responsible, for what, and in what sense The promises of technologies are criticised	The debate is being framed in controversies, and it would be more fruitful to frame it in terms of modes of co-production. It is unclear to what extent the complexity of the co-evolution between technology and morality is reflected in the scenarios The critique of the promises of STI is criticised in terms of underlying 'hard' and 'soft' negative impacts

(Continued)

Table 2. Continued.

Source	Framework(s) of reference	STI domain of intervention	Methodology & structure	Types of engagements with futures	Participants (as mentioned)	Challenge (s) tackled	Opening aspects	Closure aspects
Withycombe Keeler, Bernstein, and Selin (2019)	Sustainability-oriented RRI	Wastewater Sensing (WWS)	*Scenarios (scenario axes):* (i) Define focal questions and timeframe; (ii) identify participants; (iii) exploration of analogous technologies, key factors, and critical uncertainties surrounding the development and dissemination of the tech; (iv) brainstorm driving forces; (v) identify critical uncertainties; (vi) select scenario axes; (vii) sketch scenario storylines; (viii) write scenarios narratives; (ix) assess scenarios (SWOT analysis); and (x) create proposals for action.	Exploratory-evocative (explorations of impacts) Strategic (cost-benefit analysis in taking action)	Centre for Environmental Security WWS Researchers Legal Scholars STS and Ethics Scholars Regulators Water Managers Military	I	Scenarios are presented as a means for capability-building The whole process is performed in reflexive feedback with participants It raises important questions regarding who the innovation impacts and benefits It includes proposals for actions	The scenarios do not provide alternatives to the technology itself, rather they indirectly reify its development (albeit improving it) The variables facing the four final scenarios are public/private (ownership) and individual/ community (what is sensed) (i.e. multivariate scenarios could have been used)
Stemerding et al. (2019)	RI/TA	Synthetic biology	*Application scenarios:* (i) Define the nature of the problem and the role for SynBio; (ii) consult users and stakeholders about needs and vision; (iii) think about a business case; (iv) identify issues of risk and regulation; (v) consider design choices and requirements in this context; and (vi) combine these elements in an unfolding storyline about future SynBio *Techno-moral scenarios:* (i) consider 'soft impacts' of the application scenario; (ii) identify morally problematic situations; (iii) imagine how people might be affected and respond; and (iv) create a short story as vignette	Exploratory-evocative Exploratory-normative Strategic	Students Societal stakeholders Researchers in SynBio	II I	The intervention was extended in time (>3 years) The attention to the promotion of anticipatory capabilities in the early stages of the scientific career Highlights consideration of societal needs and definition of purpose through stakeholder involvement Considers both 'soft' and 'hard' impacts	It assumes an epistemic and moral division of labour among the actors: most of the work and visioning for the future is done by the student team (interaction with stakeholders is limited) SynBio's visions are not criticised: An enlightened view of science is promoted, in which science is presented as a problem solver Emphasis on providing solutions to social problems is addressed through an entrepreneurial approach
Schneider et al. (2021)	TA	3-D Printing	*Transformative Vision Assessment:* (i) Current analysis (qualitative social science methods); (ii) dialogue (workshops); and (iii) modulation (participatory scenarios)	Critical-hermeneutic (Analysis and dialogue) Exploratory-evocative (Building	Social scientists Stakeholders STEM researchers	III II I	It begins with a critical approach that seeks to problematise existing visions The modulation and modulation of visions is	It assumes an epistemic and moral division of labour among the actors: Scientists create the scenarios, and scientists and stakeholders discuss them

Author	Category	STI	Method	Approach	Participants	Rating	Strengths	Weaknesses
				sociotechnical scenarios) Exploratory-normative (Building more sustainable visions)			based on both normative and descriptive explorations	The variables facing the four scenarios are limited to 'inclusivity/exclusion' and 'sustainability/unsustainability' (i.e. multivariate scenarios could have been used) Scenarios where the STI at hand does not exist are not envisaged
Repo and Matschoss (2019)	RRI	Strategic R&D Policies	*Workshops*: (i) Researchers ask citizens to articulate visions; (ii) experts formulate research priorities based on those visions; and (iii) citizens asses the connections between the priorities and their visions	Exploratory-normative Strategic	Experts Citizens	II	Visions have societal issues at their centre: Politics on STI purposes comes first to prevent the problem from being framed in purely technical terms	It assumes an epistemic and moral division of labour among the actors Citizens' visions may be biased by promises, expectations, and previously circulated visions It does not problematise scenarios about the possible consequences of the STI and their plausibility and desirability
Lehoux, Miller, and Williams-Jones (2020)	AG/RRI	Implantable cardiac 'rectifier' (genetically at-risk adults)	*Techno-moral scenarios*: (i) Creation of videos depicting how the innovation works, the future context of its use, and two future scenarios; (ii) perform four face-to-face deliberative workshops; and (iii) conduct an online forum for scenarios discussion	Exploratory-evocative (explorations of ethical tensions)	38 individuals (workshops) 57 individuals (forums)	I	Involves participants of all ages. Promotes the exercise of moral imagination as a long-term prerequisite for the promotion of RRI. Even though the study was Exploratory-evocative in nature, some participants expressed concerns about scenarios' underlying promises	The scenarios are created and discussed by the organisers (i.e. not opened up to the co-negotiation between participants) The emergence of critique of visions was dependent on the contingent dynamics of the exercise, not methodologically promoted It is not clarified how the intervention modelled the dynamics of STI co-production
Kera (2020)	AG/RRI	Blockchain and decentralised ledger technologies	*Simulation game*: (i) Immersive experience in a fictional 'smart village'; (ii) deliberative role-play and conclusions of concerns; (iii) develop and prototype based on '(ii)'	Exploratory-evocative Strategic	Citizens	I	Enacts anticipatory capabilities through interactive exercises in a wide range of issues (design prototyping, policy, regulation issues) Supports contextual framing Contemplates the moratorium of the technology as an option	It is unclear to what extent and how these capabilities were transferred to STI practice Participants are 'confronted' with scenarios, which frame the simulation game

the prominence of the precautionary consequentialist tradition. This tradition has typically understood responsibility in terms of the exploration of future impacts in the service of (i) the minimisation (or avoidance) of those impacts that are considered negative, and (ii) the maximisation of those impacts that are considered positive. Once the potential impact 'X' has been identified and deemed negative, being responsible has typically been conceived as the minimisation or avoidance of 'X'. Of course, the question of on what and whose grounds something is judged to be 'positive'/'negative' is not trivial and should be on the table (which is often not the case in these exercises).

This tendency to link anticipation to the problematisation of STI impacts (and especially negative ones) is particularly problematic on account of the fragmentation previously noted. Not only is anticipation often linked to the problematisation of impacts, but it is usually *reduced* to this. The downside is not so much that anticipation is predominantly related to the challenge of problematising outcomes (i.e. 'I.'), but that anticipation is predominantly activated only in relation to this challenge. This is highly detrimental for a comprehensive operationalisation of AG, RRI, RI, or TA through foresight exercises, which should include not only the problematisation of outcomes, but also the problematisation of STI purposes, processes, and visions/expectations/promises.

Indeed, another central challenge of AG, RRI, RI, and TA is to open up the purposes to which STI is oriented (i.e. 'II.'). While acknowledging the contingency, impossibility of control, and non-linear nature of STI, the goal is to problematise in real time the nature of the socio-political and techno-moral worlds we mould through STI practices. While this is the case in theory, analysis shows that such problematisation of the STI ends does not always occur in practice and that when it does occur, this problematisation has various methodological-operational limitations.

In fact, only five sources were identified that explicitly problematise the socio-political purposes of STI. However, these five works present a variety of methodological challenges. For example, Mann (2015) and Stemerding et al. (2019) problematise the purposes, but this problematisation occurs within the frame previously established by projections about the potential merits and pitfalls of the STI in question (the former in terms of future impacts, the latter in terms of potential niches where STI could become valuable or profitable). This means that the problematisation of the purposes is not so much about the socio-political significance of the STI at hand, but rather the modalities under which the STI must be promoted in order not to be socio-politically (so) problematic in the future. In this way, the exercises subtly reify the needs and goals of the STIs under study. This problem of reification could be solved by starting the process with an exploratory-normative exercise, as is the case with Repo and Matschoss (2019)'s exercise. However, this exercise is by no means unproblematic either. Its main problem is that it does not consider that citizens' visions can be distorted by promises and visions, and therefore critically reify the STI lines that represent those visions. For this very reason, Schneider et al. (2021) suggest that the core of the intervention should begin with a critical-hermeneutic engagement with participants' anticipatory assumptions: The aim is to counteract the performative power that some visions might have later in the intervention when goals and implications are explored and reflected upon.

The work of Schneider et al. (2021) is indeed the only one of the analysed sources that integrates the critical-hermeneutic approach and thus the only one that addresses the

'III.' challenge of AG, RRI, RI, and TA. Moreover, the work of Schneider et al. (2021) is the only one that addresses the three challenges of AG, RRI, RI, and TA. However, the way the work is structured has some shortcomings, the most important being that the possibility of the non-existence of 3D printing is not presented in any scenario, or that 3D printing has been presented as a disruptive element in all scenarios (thus ultimately reproducing the visions that 3D printing campaigners are interested in). The debate should no longer be methodologically closed, so that a moratorium could be conceivable as a plausible scenario. Moreover, as with many other exercises, there is little evidence on how the anticipatory considerations and enabled knowledge were later integrated into STI practice.

As previously mentioned, the assessment of the anticipatory dimension cannot be separated from other dimensions that permeate AG, RI, RRI, and TA, such as reflexivity, inclusion, or responsiveness. Regarding reflexivity, it has already been suggested that the different forms of enabling anticipation exert different degrees of reflexivity on STI. In terms of inclusivity, the presence of closure mechanisms in relation to the actors coming into play and their (sometimes too passive) role in the processes of co-creating and assessing scenarios is worth noting. Many of these exercises remain undertaken within the framework of an epistemic, political, and moral division of labour (e.g. there is very often a demarcation between the group of actors who co-construct the scenarios and the group that co-assesses them). Many of the scenarios are created by desk research and then presented to various participants for critique and feedback; participants who are in turn referred to using a variety of labels, each having different semantic connotations. These mechanisms of subtle closure contrast with exercises wherein all actors collectively co-produce the very scenarios that will later be the subject of collective critique and a source for reflection. These more open exercises, being a minority, are expected to allow for a more inclusive and responsive process in terms of the underlying assumptions to be considered, thus opening-up the alternatives to be considered. The findings of the analysis suggest that more attention needs to be given to (i) the criteria underlying the selection of actors, (ii) the ways in which these actors are referred to and the biases or constraints associated with them (they are heterogeneously presented under labels such as 'stakeholders', 'lay people', 'public', 'citizens', 'experts', etc.), and (iii) the forms of participation that are actually facilitated in order to strengthen their voices and allow for a more robust socio-political critique of STI. As Irwin, Jensen, and Jones (2013) argue, critique should be 'a key component' of public engagement to improve the quality of knowledge co-production processes. Finally, regarding responsiveness, in most cases there is no demonstration of how these actions have subsequently impacted on STI systems and how public concerns have been reflected in subsequent STI practices and developments. In this sense, there is a need for more in-depth analysis and monitoring of the ways in which these exercises transform STI practices.

Many of the above limitations are of course attributable to time and socio-material constraints (which are unavoidable). However, many other limitations are due to methodological criteria (which are certainly avoidable or minimisable). The discussion above is not intended to highlight things we might be doing wrong, but rather to suggest what we could be doing better. The emphasis on closure in the above critical review should not blind us to the benefits expressed in the exercises cited. These undoubtedly promote more robust forms of STI co-production than the mainstream ones. However, if the

ultimate ambition is to open up STI modes to more socio-politically robust forms of co-production, it is worth discussing how the structures that underpin our interventive methods narrow the spaces for discussion and problematisation.

A comprehensive methodological proposal to operationalise anticipation

This section proposes a tentative structure of a (multi-)foresight process to support the operationalisation of AG, RRI, RI, and TA. This procedural anticipatory structure is presented as 'a methodology of inquiry-in-interaction, which increases reflexivity of the [STI] developments' (Rip and Robinson 2013, 37). The tentative structure of the multi-foresight exercise seeks to minimise the two main limitations identified in the previous section: (i) the fragmentation of foresight exercises in addressing the main challenges of AG, RI, RRI, and TA, and (ii) the problem of reifying futures.

While the problem of fragmentation is addressed through a systematic problematisation of the diverse STI domains (purposes, processes, and outcomes), the problem of the reification of futures is addressed through the integration of a critical-hermeneutic approach to future narratives and representations during the intervention. Since some degree of reification is inescapable, the enemy is not reification per se, but rather *uncritical* reification. The aim is to introduce 'upstream' reflexivity in STI practices through foresight so that the sociotechnical futures that are in constant co-production are anticipatorily shaped in the most transparent, inclusive, and reflective way possible (Jasanoff 2020).

It should be noted that the fact that the methodology proposed here aims to be less vulnerable to these two problems does not mean naively supposing that it will not be subject to the limitations and contingencies inherent in any interventive operationalisation. The exercise does not claim to be a solution or panacea. Instead, it is a tentative ideal-typical proposal that can be further critiqued and elaborated. Ultimately, it aims to promote intervention mechanisms that, from their conception, are more sensitive to the reification of futures and attend to the politics of anticipation in which they are embroiled, and which are propagated through them.

The multi-foresight architecture proposed is structured in three phases: the *ex-ante* (phase 1), *ex-dure* (phase 2), and *ex-post* (phase 3). Phase 2 comprises the core activities for activating the anticipatory heuristic and is itself subdivided into four subphases (see Figure 1). The distinction between the subphases is determined pragmatically and heuristically by the STI domains that are primarily problematised and by the type of socio-epistemic activities required to carry out this problematisation. Needless to say, the STI domains to be problematised are constitutively interwoven. Problematisation in one dimension may influence problematisation in another. In this sense, and although the division of foresight dynamics into (sub)phases may make it appear that these have a linear progression, there might (and should) be intense iterative processes and feedback loops between them, resulting in multiple rounds of ongoing 'social learning'. Indeed, iterativity, nonlinearity, and dynamism are widely recognised as characteristics of foresight exercises (e.g. Popper 2008, 45). Iteration is important because it allows going back and forth between the different (sub)phases. On the one hand, iterativity between the general phases is important so that foresight itself remains open to reformulation and enrichment throughout the whole process. On the other hand, iterativity between the subphases of phase 2 is important in order to make connections between
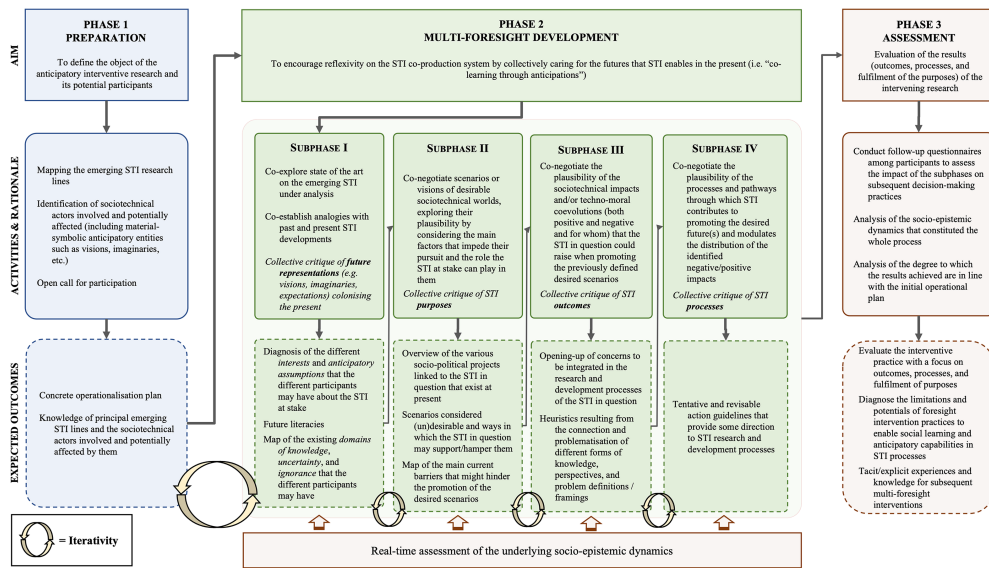
Figure 1. General schema of the proposed methodological procedure for a comprehensive operationalisation of foresight/anticipation practice.

the different STI domains that are problematised (i.e. outcomes, purposes, processes, visions/narratives/promises/expectations). In the following, these (sub)phases and their respective rationales are further elaborated.

Phase 1: preparing the interventive practice

All interventive exercises begin with the delineation of the niche of intervention. The definition of this intervention niche involves consideration of at least (i) the field or domain or STI lineage that is the object of the intervening design, (ii) the actors who should or could a priori be involved in the exercise, (iii) the heuristics that it seeks to activate, and (iv) the techniques of engagement with representations of the future that will be used to this end. Clearly, these four elements, along with many others, are interrelated. The determination of each element has implications for the appropriate consideration of the other elements (Figure 2).

The team conducting the interventive research needs to be particularly sensitive and self-reflective about the contextual factors that may influence their choices on these variables. Reflexivity is required insofar as their decisions will shape the alternatives that will be opened up or closed down and in relation to which aspects these apply.

One of the factors that require special attention in this process are the hermeneutic circles and sociotechnical meanings in which the anticipatory intervention may be entangled. As Grunwald (2020) argues, the choice of which technology or innovation to make the subject of assessment is often conditioned by the sociotechnical meanings that have emerged around them. If an STI field has attracted the attention of certain scholars to consider it the target of their interventions, it is because there have been prior socio-political dynamics and a proliferation of meanings that have helped to elevate its
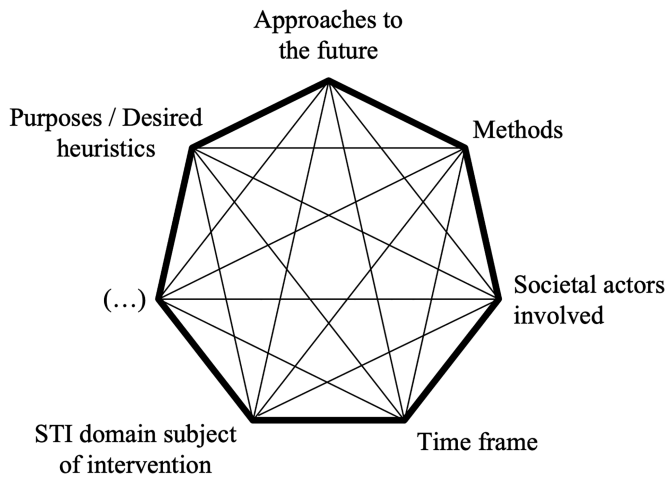
Figure 2. Interrelated factors in foresight practices.

importance as an object of responsibility. Deciding on the STI line for which the exercise is being conducted is already a first relevant closure point (it draws attention to a particular STI line to the detriment of possible others).

Another important factor is which actors should be involved in the foresight process to problematise the STI in question. A call for participation is inevitable – even if the call remains open. A key question is which actor profiles with their respective values, desires, expectations, capabilities, and knowledges will be primarily involved. Furthermore, there is a need to consider how the involvement of actors whose socio-material conditions do not allow or facilitate their participation can be supported. Closing-down the diversity of different contributions during the negotiation process may impoverish the concerns raised as well as reproduce prejudices and 'business-as-usual' practices. If the focus of the exercise is to promote the capabilities of specific actors (e.g. futures literacy capabilities), the question of which actors are given the opportunity to practise and improve these is non-trivial.

The 'selection' of participants is also important because the exercise is meant to involve all of them 'during the whole process' (European Commission 2013b, 4; von Schomberg 2013). Obviously, this would be the ideal, and diverse constraints may limit inclusiveness. The participation of a plurality of actors is supported both by fulfilling the 'inclusion/engagement' normative dimensions of AG, RRI, RI, and TA (see Table 1) and by promoting a more epistemically robust critique. While a plurality of voices does not guarantee such robustness, it is expected to enrich the range of perspectives and broaden central and hegemonic narratives (Popa and Blok 2022), minimise potential epistemic and hermeneutic (Fricker 2007) or argumentative (Bondy 2010) injustices, and identify, make visible, and minimise potential biases in research (see Braun and Starkbaum 2023) and agenda-setting (e.g. Boudreau et al. 2016) processes.

Phase 2: the multi-foresight process

The second phase of the intervention exercise is considered the heart of the interventive process, as it is here that the possibilities of STI are discussed, and the anticipatory

heuristics are closed/opened. It is in this *ex-dure* phase that the politics of anticipation are at play. These politics of anticipation are meant to be mobilised and scrutinised through negotiation processes regarding the (im)plausibility and (un)desirability of pasts, presents, and futures (Selin 2011). During these (im)plausibility and (un)desirability deliberations, a great heterogeneity of interconnected and contextual variables (e.g. epistemic, normative, axiological, emotive, aesthetic) come into play (Adam and Groves 2007; Selin and Guimaraes Pereira 2013; Ramírez and Selin 2014; Urueña 2019; Fenton-O'Creevy and Tuckett 2022). These variables may refer strictly to the STI under study and/or to more general concerns (e.g. visions and narratives encoding frames on cultural and political orders).

The multi-foresight exercise outlined here proposes to divide this heart of the process into four subphases, each of which focuses on facilitating engagement with the future under different modalities and dispelling temporality from different dimensions (see Table 3). The socio-epistemic activities facilitated in these subphases, as well as the challenges they target, determine (i) the scope and depth of the intervention. Similarly, the way in which engagement with the future is structured determines (ii) the gradients of uncritical reification of futures (i.e. which aspects are considered (im)plausible and (un)desirable and which aspects therefore become non-problematisable). On the one hand, in view of the problem of fragmentation, the multi-foresight exercise proposes that its four subphases comprehensively address the main challenges that AG, RRI, RI, and TA seek to address (Section 2). On the other hand, in the face of the problem of uncritical reification, the exercise is structured in such a way that it encourages starting the foresight process with a critical-hermeneutic approach to the futures and narratives that colonise and enframe the present (first subphase) and

Table 3. General challenges raised in each subphase of phase 2, areas of temporality affected, and promoted modes of engagement with the future.

Subphases of phase 2	Principal challenge associated with responsible innovation	Main temporal domains involved	Type of engagement with futures
Subphase 2.I	'I.': To explore 'endogenous futures' 'III.': To promote critical capacities concerning future representations and ways of using the future that de facto colonise the present of STI governance dynamics (both formal and informal)	*Present*: Identifying current STI developments *Past*: Revisiting previous STIs, experiences *Deflation of futures-in-the-present*: Identification and critique of promises, visions, expectations, imaginaries, and 'endogenous futures'	*Critical-hermeneutic*: Identify and emancipate from futures colonisations in the present
Subphase 2.II	'II.': To problematise the sociotechnical configurations, purposes, and orientations of the STI	*Present*: Analyse the available resources and the limits imposed by current sociotechnical orders and their materiality *Future*: Opening-up of the set of sociotechnical desirable futures considered	*Exploratory*: Opening-up the desirable futures
Subphase 2.III	'I.': To explore the different impacts that might coevolve with the development of the STI	*Future*: Opening-up the range of issues and concerns considered regarding the STI at stake	*Exploratory*: Opening-up the potential impacts
Subphase 2.IV	'II.': To problematise the processes and orientations of the STI	*Future*: Draw up guidelines for current actions to promote the realisation of the desirable futures already problematised	*Strategic*: Outlining guiding actions

prioritising normative or visionary exploration over hypothetical-projective exploration (second subphase).

In the following, each of these subphases will be briefly explained. The focus is on their respective justifications or their ideal-typical function in dealing with the problem of fragmentation and minimising the problem of uncritical reification. The scheme presented is generic enough to be re-adapted in different contexts and in relation to different STI domains. At the same time, it is concrete enough to illustrate the importance of the structure to anticipatory exercises. Structuring organises the different ways of engaging with the future and relates them to each other. This sequence and relationships are key to intervening practices.

Subphase 2.I – setting the stage of plausibility and desirability negotiations

The first subphase aims to prepare certain grounds for the subsequent negotiation of the plausibility and desirability of futures. These bases are intended to be established through the generation of reflexive dynamics that address both past and present temporality, as well as the critique of the futures-in-the-present that materialise in visions, expectations, and sociotechnical imaginaries.

As Derbyshire and Wright (2017) argue, many scenario-building exercises currently devote 'little attention to the consideration of either the present state or how it has come to be', even though the treatment of the past and present can generate many heuristics that can be particularly valuable for STI responsibilisation. Given that the lenses or assumptions through which we look at the past and present are multi-layered (different actors could underline different dimensions of the present and the past), and many of the discrepancies about the future will be driven by divergences of the present and past, it is necessary to address and co-negotiate the plausibility of these from the outset.

The aim of fostering dynamics of reflection on the current state is not so much intended to establish a common ground (i.e. to impose a uniform or monolithic state of the art), but rather to consider the different perspectives on the present from which actors perceive and interpret reality; both in relation to the sociotechnical system in which the intervention takes place, and more specifically in relation to the STI at stake. Indeed, it has been recognised in the literature that the plausibilisation of other futures also depends on the plausibilisation and possibilities of reframing the presents (Urueña 2019; Fischer and Dannenberg 2021).

It might also be particularly fruitful to problematise how we relate the past to the present of the STI in question, as well as the past to its future. Schwarz-Plaschg (2018a, 153), for example, has pointed out how analogies from the past (i.e. comparisons of the past and the present) are used 'to make arguments and enforce framings'. She has also highlighted how analogical imagination and enhanced analogical sensibility can help promote RRI (Schwarz-Plaschg 2018b). The case of nanotechnology is a clear example of a non-presentist field where the use of both the pasts and futures has helped to mobilise the imaginations and opinions of different publics (favourable or unfavourable to legitimise nano-development) (Mody 2004; Selin 2006; Schwarz-Plaschg 2018b). Despite the value of past knowledge for STI responsibilisation, there are calls to increase both the use of this knowledge and its problematisation (Zimmer-Merkle and Fleischer 2017). The inclusion of past temporality intended here also underlines this.

The case of the use and mobilisation of analogies illustrates that the colonisation of the spaces of plausibility and desirability is not carried out by future representations alone. However, this does not mean that the latter are excluded. The inclusion of the problematisation of futures-in-the-present is intended to prevent the performative power of promises, expectations, and sociotechnical imaginaries from limiting the later explorations of the multi-foresight process. As Groves (2013, 186) notes, 'technological future imaginaries may help to prevent scrutiny of assumptions about innovation pathways and to exclude alternative visions of the future from discussion, thus making progress on the procedural elements of RRI more difficult'. The proposed problematisation of these futures-in-the-present from the outset aims to enable a basic form of 'futures literacies' (Miller and Sandford 2019) that neutralises *as much as possible* their power to reify certain possibilities and thus impede the opening-up of alternatives to be considered in later subphases. While it would be naïve to assume that these future representations will no longer have power in subsequent phases, it is possible to assert that the necessary and possible mechanisms have been created to ensure that their impact is lessened as much as possible.

In conclusion, this first subphase activates the negotiation of plausibility as an epistemic process in the service of critically opening-up the past, present, and futures-in-the-present that de facto colonise and modulate the way we imagine, explore, and confront reality. This first subphase is ultimately proposed as a social learning exercise aimed at opening/acquiring capacities for opening-up the representative artefacts that, exploiting temporality in each historical moment, constrain our explorations and visions of the future, thereby closing-down the spaces of possibility deemed desirable and plausible. The purpose is to operationalise the demand to begin every exploration by such critical assessments (Grin and Grunwald 2000; Nordmann 2014), as well as to offer a response to calls for the introduction and promotion of hermeneutic anticipation (van der Burg 2014; Grunwald 2020).

Subphase 2.II – giving our STI practices a desirable and plausible direction

In contrast to exploratory foresight exercises that start from 'product scenes' and problematise their (un)desirability and (im)plausibility later, this second subphase of the multi-foresight exercise aims to problematise upfront the problems, challenges, or purposes with which we align the STI. Ultimately, the aim is to discuss the sociotechnical and techno-moral worlds to which the STI is expected to contribute and the ways in which it can/could contribute to them. This way of structuring the debate prioritises discussion of the plausibility and desirability of the problem-framing and policy purposes underpinning the STI in question over exploration of its potential impacts. The aim is to address the problem already explicitly identified and criticised by von Schomberg (2012, 7):

> [F]oresight projects could benefit from a prior analysis of potential relationships between types of plausible technological pathways and particular (social) problem-definitions, rather than starting with 'naïve product scenes,' (…) thereby methodologically ignoring the underlying problem definitions.

Suppose we co-design an anticipatory process. Its first exercise consists of co-projecting and negotiating the (im)plausibility and (un)desirability of sociotechnical scenarios that could arise from stratospheric sulphate injection as a measure in the face of climate change. These scenarios will depict diverse negative and positive configurations that the various participants are able to envision and justify. However, once we enter the debate on the

(im)plausibility and (un)desirability of these scenarios, we would be doing so not only at the expense of taking the technology itself as plausible but also indirectly accepting a way of dealing with the climate change problem that can and should be explicitly problematised. For example, we would be assuming the Enlightenment paradigm of technological solutionism, where the solution is posited as technical rather than sociotechnical and organisational. The 'product scene' enframes a definition of the problem and its corresponding resolution. The problem is climate change, and it is enframed as a technical problem – thus with its corresponding technical solution. The solution is to solve the effects of climate change by minimising the effects caused by our current forms of industrial production. The 'product scene' presents a solution to one of our Grand Challenges, but it frames those solutions so that it shields the causes of the problem from problematisation, focusing only on counteracting the effects. It situates us in a scenario where the aim is to solve the effects of climate change caused by our current systems, but without promoting a fundamental debate on the necessity and relevance of changing our current sociotechnical systems and their productive constellations. This way of framing the problem subtly promotes the reification or perpetuation of the same organisational scheme that causes the problem by not promoting the conception of alternative socio-economic and techno-industrial forms of organisation that would address or minimise the problem at its root.

The absence of an explicit opening-up mechanism to unpack the potential relationships between types of plausible STI pathways and particular problem definitions would entail leaving it to chance whether these relationships are maintained or transformed. The aim of interventive anticipatory exercises is not to leave these issues to chance, but to promote reflexivity as deeply as possible (Guston 2014). The aim of subphase 2.II should therefore be to explicitly de- and reconstruct the problem definitions and the STI purposes these embody. This includes, for example, questioning the extent to which these problem definitions and STI purposes correspond to the wishes, expectations, and interests of the social actors involved. The proposed critique should be not only deconstructive but also constructive. The exercise has to remain open to the suggestion of alternatives. If there are voices that consider the STI purposes and issues to be 'implausible' and/or 'undesirable', these voices should suggest 'plausible' and 'desirable' ones as a counterpoint.

This collective problematisation of the futures considered '(un)desirable' and their grounds/frames can obviously lead to the activation of problematisation processes that will require calling on or revisiting the results of the previous subphase (e.g. taking into account the extent to which narratives and meanings close the purposes). Furthermore, this problematisation may also require activating socio-systemic processes that would correspond to the next subphase (e.g. conducting outcomes explorations of either the socio-technical project in question or of those alternatives considered most desirable). It is therefore expectable that iterative and back and forth processes will exist between these subphases. The rationale for placing this subphase in this second position within the structure is to prevent problem definitions from uncritically pre-setting possibility spaces outside of which alternatives cannot be envisaged.

Subphase 2.III – enriching our normative futures
Once the futures deemed desirable have been explored, it is important to enrich them with reflections on the possible negative/positive outcomes that might arise both in

the process of pursuing these futures and in the hypothetical situation in which these become a reality (to some degree).

The reason for such hypothetical-projective explorations lies in the need to problematise that the pursuit of a desirable future is neither neutral nor free from tensions or imbalances. As Adam and Groves (2007, 2011) observe, any form of future-making is a form of future-taking, and even the future(s) negotiated as 'desirable' would not be free of depicting and embracing power asymmetries. This process aims precisely to explore the sociotechnical and techno-moral co-evolutions that might occur. Questions around (i) what effects there might be (e.g. effects on techno-moral or sociotechnical orders) and (ii) what the distribution of these effects is (e.g. for whom they are seen as positive or negative and under what conditions) would be the subject of social examination and enrichment. This phase is thus ultimately about enriching the normative futures co-negotiated in subphase 2.II through reflexivity.

At this point, one might ask whether the exercise does not reify the normative future (s) dealt with in subphase 2.II. The answer is that a certain degree of reification is unavoidable. If any kind of action is to be anticipatorily informed, it is necessary to close the space of possibilities under consideration. In this sense, the problem here is not so much reification per se, but *uncritical* reification. In other words, the problem is the reifications produced on the basis of futures that are little discussed and negotiated, and thus on futures with little socio-epistemic and socio-political legitimacy. The multi-foresight process therefore aims to minimise this problem by discussing the consequences within futures that have been previously problematised.

The futures of subphase 2.II that set the frame of this subphase 2.III, however, must be kept open for re-examination. The results of subphase 2.III may lead to a reconsideration of the visions of desirable futures themselves by reactivating the previous subphase.

Subphase 2.IV – co-creating action plans

The fourth and final subphase has the difficult task of translating all the heuristics coming from the previous opening-up processes into practical guidance for the STI exercises. Ultimately, as is common in strategic and visioneering exercises, the aim is to create an execution plan. This essentially consists of identifying how, given the resources available and the diagnosis of the current situation previously established in subphase 2.I, actions can be triggered to promote the emergence of the negotiated plausible and desired future(s).

There are at least two aspects of this *ex-dure* subphase that are important to comment on. The first refers to the need to keep the implementation plan under continuous review, as an open plan. This is important to be able to adapt it to the contingencies that emerge during the process. Moreover, it is also important to insist during the mediation process that processes and plans are fallible in nature, and their significance is merely heuristic-orientational. Even when the outlined plan is accurately followed, it is important to emphasise that the desirable future may not be achieved (although following the instructions will more likely approximate this than otherwise). Ultimately, these forms of mediation are important to prevent the multi-foresight exercise from falling into the illusion of looking at the future as a space that can be the target of our design. The future, in this sense, must be maintained throughout the process as a space that is intrinsically uncertain, complex, contingent, and relatively open.

Table 4. Examples of key questions to address during the foresight assessment process.

	Examples of key question(s)	Potential key heuristics
Processes	• What underlying dynamics of anticipatory knowledge co-creation underpinned the exercise? • How were the various anticipatory capabilities intended to be developed or reinforced? • Which/whose voices were heard/silenced, which/whose capacities were enhanced, and which/whose spaces of possibility were selected/discarded, and on what grounds	Identification of power dynamics and hampering (f)actors functioning during anticipation processes Types of relationships and their respective qualities and asymmetries (e.g. identifying instances of argumentative and epistemic injustices)
Outcomes	• What heuristics and/or anticipatory knowledge or capabilities were de facto activated? (in the long/medium/short term) • Did the hegemonic dynamics and realities of STI change? Which ones? When? To whom and in what sense?	Knowledge about the emergence of immediate, intermediate, and final heuristics (including those unexpected or undesired) and how they evolved in time (whether they were reinforced, atrophied, or maintained) Identification of the actors who benefited (or not) from the results and in relation to which aspects
Purposes	• To what extent do the outcomes match the initial operationalisation plan?	Reflection on the intervening performance and the adequacy of the initial operationalisation plan

The results of subphase 2.IV may lead to revisions of the futures or visions considered plausible and desirable, or of the specific issues considered in these. As a result, it may be possible to return to earlier stages of the multi-foresight process (e.g. revisiting the findings of subphases 2.II and/or 2.III).

Phase 3: foresight dissemination and assessment

The third phase includes all the activities that take place after the completion of the multi-foresight exercise. These *ex-post* activities focus mainly – but not only – on (i) the dissemination of the results and (ii) the systematic and mainly qualitative (although it may be complemented by quantitative data) monitoring and evaluation of the foresight processes, outcomes, and purposes (Table 4). The systematic and *ex-post* nature is precisely what distinguishes this evaluation from the evaluation that could (and should) be carried out in real time throughout the whole operationalisation process.

The realisation of this assessment would have as a necessary condition the creation of documentary records of the processes (e.g. audio, video, field notebooks). These data and records could then be analysed and interpreted using various well established qualitative research methods in the social sciences and humanities – especially those typically applied in the STS. Conducting this process evaluation could serve to draw practical operational lessons to feed into subsequent anticipation exercises.

Conclusions

AG, RI, RRI, and TA propose anticipation as a key dimension through which to shape more responsible innovation. This paper has provided an exploratory overview of how

anticipation has been operationalised recently for AG, RI, RRI, and TA. This overview points to an operational fragmentation in addressing the theoretical challenges associated with anticipation. In theory, anticipation is mobilised to delve into at least three inter-related challenges: Enabling a socio-politically robust exploration of STI (I.) outcomes ('positive'/'negative', 'soft'/'hard'), (II.) purposes and processes, and (III.) critiquing the performative power of STI visions, imaginaries, promises, and expectations. However, in practice, anticipation is carried out with a narrow focus on a few of these challenges (thus leaving challenges and issues unproblematised and subtly promoting reification of some frames and futures).

The heterogeneous and simultaneously fragmented nature of anticipatory practices has motivated the proposal of a flexible and general qualitative foresight process. The foresight process outlined here proposes to structure the exercise from its very inception into self-reflexive processes regarding how the framing of the interventive exercise is itself framed and fixed (phase 1, *ex-ante*). This means, among other considerations, that the openness and closure mechanisms involved in the selection of the STI as a target for inter-vention (to the detriment of others) or in the invitation of actors to participate in the process should be critically considered. Let us imagine that in this first or *ex-ante* or pre-paratory phase, it was decided to carry out the anticipatory exercise on stratospheric sul-phate injection as a sociotechnical measure in the face of climate change. Moreover, a heterogeneous group of actors have been reflexively and critically identified and invited to participate in order to have different perspectives and interests among these actors (in relation either to this technology in particular or to more general concerns).

The next phase (i.e. phase 2, *ex-dure*) would encompass the socio-epistemic and delib-erative processes for the activation of anticipatory heuristics. The structure proposes to initiate the process by enacting a critical-hermeneutic approach (subphase 2.I). This approach would include activities focused on collectively identifying the lines of research that point to the development of this STI, reviewing similar technologies that are occur-ring in the present or have occurred in the past, and in particular critiquing the frames, narratives, and futures (e.g. visions, imaginaries, promises) that are mobilised in relation to this STI. The goal is to problematise the (perspectives on) past and current state of affairs and simultaneously to avoid (or minimise) that the assumptions and frames underlying the futures that are mobilised in the present uncritically foreclose the space of potentially conceivable alternatives in later subphases. The issues addressed and aspects that emerge will contingently depend on each process and the mediation per-formed. However, one might expect, for example, the identification and problematisation of the myth of technological solutionism or technical hubris that underlies this STI in the face of the climate change challenge.

The next subphase (2.II) would address considerations of the (im)plausibility and (un)desirability of this sociotechnical project by focusing on the purposes underlying its development. This would include problematising the values and sociotechnical orders that this sociotechnical project could (re)produce or the normative frameworks that it contains, as well as assessing their (un)desirability. For example, it would be per-tinent to question the extent to which this technological project does not reproduce or perpetuate the very socio-economic orders that have caused the problem it seeks to address (i.e. climate change), in what ways and in what gradations different actors benefit or are disadvantaged by it, and to what extent alternative STI projects or ways

of addressing the problem are (im)plausible and (un)desirable. The aim is to open up a variety of alternatives (and to discuss the reasons justifying them).

Once the (un)desirability and (im)plausibility of the sociotechnical orders and normative frames that the STI project might encode and promote have been assessed, the intervention may follow different paths depending on its constitutive and contingent dynamics. These pathways cover a spectrum of possibilities ranging from declaring stratospheric sulphate injection to be completely undesirable and proposing alternative STIs and approaches to climate change, to considering its partial desirability and proposing only some revisions. The next subphase (2.III) would focus on assessing and enriching these alternatives/revisions to stratospheric sulphate injection discussed earlier by problematising their respective potential outcomes (in the broadest sense). The last subphase of this second phase (2.IV) would focus on clarifying and problematising the different processes that could be activated (and the associated difficulties) for promoting the desirable futures deliberated on in 2.II and enriched in 2.III.

Finally, the anticipatory procedure is recommended to be completed by a follow-up exercise (e.g. interviews, surveys, field studies) to assess the scope and depth of the capacities and/or heuristics co-shaped (phase 3, *ex-post*).

This methodological structuring is ultimately designed to respond both to the fragmentation regarding the STI dimensions that are problematised (i.e. outcomes, processes, purposes) and to the need to ensure that the problematisations of STI through futures 'begin with vision assessment' (Nordmann 2007, 41). The 'upstream' (meta-)reflexivity that should guide the foresight process renders it less susceptible – though never immune – to the uncritical reification of visions, imaginaries, and expectations.

While the course of the process from subphase 2.I to 2.IV acquires a certain directionality, in practice the process does not need to be (nor is it desirable for it to be) strictly linear. Each of the subphases could lead to a revision of the results of the previous subphases, which supports back-and-forth learning processes and thus accommodates iterativity. It is obvious that the problems of purposes, outcomes, and processes are constitutively interconnected. The open and iterative nature of the architecture allows for transitions between the critical reflective activities that characterise the different subphases of phase 2, thus enabling interrelated problematisation of the different dimensions and challenges of the STI at stake. Iterativity can be extended indefinitely and concluded in accordance with the final implementation schedule of the intervention project.

This structure is flexible and general enough to be adaptable both to the various constraints that may limit the intervention project (e.g. time, material and human resources, the context) and to the specific needs of the STI in question. For example, it can be conducted in one or several interactive workshops, depending on available resources and needs. However, the architecture is specific enough to promote a diversity of socio-epistemic activities that allow for an intersecting, reflexive, and critical approach to the different dimensions and challenges of STI (i.e. outcomes, processes, goals) and for minimising the reification of hegemonic futures and narratives related to STI (e.g. imaginaries, visions, expectations).

The proposed procedural anticipatory architecture is, of course, neither a panacea nor a guarantee for the promotion of responsible STI, nor is it intended to be. The heuristic disruptiveness of the practices consistent with the architecture will inevitably be modulated by the socio-material constraints and resistances imposed by the prevailing trends

of the sociotechnical milieu in which these practices are embedded and which they seek to transform (Urueña, Rodríguez, and Ibarra 2021; Urueña 2022). The purpose and contribution of the anticipatory structure is that it stimulates and affords by its very design a broader problematisation of STI.

By emphasising the importance of the design and procedures that constitute anticipatory-interventive practices, the article has highlighted the responsibility of social scientists in shaping and opening certain spaces of reflection (while closing others) therein. The emphasis is on attending to the futures or sociotechnical worlds, and STI pathways that are (not) envisaged and problematised throughout anticipatory interventive process (i.e. on attending to the spaces of (im)plausibility and (un)desirability that are prefixed). As such, this article constitutes a further tentative step in inquiring into the relations between the politics of anticipation and the architectures of anticipatory methodologies (Macnaghten 2021). If this article prescribes anything, it is first and foremost that there is a need to further problematise how interventive anticipatory tools can be developed to assist in the difficult but laudable task of shaping better future sociotechnical worlds through the shaping of more socio-politically robust STI practices.

Notes

1. Long historical-conceptual roots nourish, support, and inspire AG, RRI, RI, and TA. For more on the origins of these frameworks, see: Barben et al. (2008) and Karinen and Guston (2009) on AG; von Schomberg (2013) and Owen, Macnaghten, and Stilgoe (2012) on RRI; Stilgoe, Owen, and Macnaghten (2013) and Owen and Pansera (2019) on RI; and Grunwald (2019) and Grunwald (2009) on TA.
2. The drivers constituting the fragmentation in the problematisation of the dimensions of STIs are heterogeneous. While exploring the causes of this fragmentation would be a necessary and interesting task, this article is limited to a tentative diagnosis of its existence. Ultimately, the aim is to encourage the design and adoption of anticipatory processes that are not a priori limited to problematising a particular subset of the issues raised by STIs. All this is done in awareness that no method is a panacea. Rather, it is a matter of problematising which "affordances of critique" intervening processes enact.

ORCID

Sergio Urueña 🔵 http://orcid.org/0000-0002-1084-2709

Notes on contributor

Sergio Urueña received his PhD in Philosophy, Science and Values in the Department of Philosophy at the University of the Basque Country UPV/EHU. His research focuses on epistemological and methodological issues related to operationalizing anticipation to promote more socio-politically robust research and innovation governance dynamics. His interests include STS, responsible innovation, anticipation and futures studies, and political philosophy of technology.

References

Adam, B., and C. Groves. 2007. *Future Matters: Action, Knowledge, Ethics*. Leiden: Brill.

Adam, B., and C. Groves. 2011. "Futures Tended: Care and Future-Oriented Responsibility." *Bulletin of Science, Technology & Society* 31 (1): 17–27. doi:10.1177/0270467610391237.

Arnaldi, S. 2018. "Retooling Techno-Moral Scenarios. A Revisited Technique for Exploring Alternative Regimes of Responsibility for Human Enhancement." *NanoEthics* 12 (3): 283–300. doi:10.1007/s11569-018-0329-6

Barben, D., E. Fisher, C. Selin, and D. H. Guston. 2008. "Anticipatory Governance of Nanotechnology: Foresight, Engagement, and Integration." In *The Handbook of Science and Technology Studies. Third Edition*, edited by E. J. Hackett, O. Amsterdamska, M. Lynch, and J. Wajcman, 979–1000. Cambridge, MA: MIT Press.

Bechtold, U., L. Capari, and N. Gudowsky. 2017. "Futures of Ageing and Technology – Comparing Different Actors' Prospective Views." *Journal of Responsible Innovation* 4 (2): 157–176. doi:10.1080/23299460.2017.1360721.

Bell, W., and J. K. Olick. 1989. "An Epistemology for the Futures Field: Problems and Possibilities of Prediction." *Futures* 21 (2): 115–135. doi:10.1016/0016-3287(89)90001-3.

Boenink, M. 2013. "Anticipating the Future of Technology and Society by Way of (Plausible) Scenarios: Fruitful, Futile or Fraught with Danger?" *International Journal of Foresight and Innovation Policy* 9 (2/3/4): 148–161. doi:10.1504/IJFIP.2013.058608.

Bondy, P. 2010. "Argumentative Injustice." *Informal Logic* 30 (3): 263–278. doi:10.22329/il.v30i3.3034.

Boudreau, K. J., E. C. Guinan, K. R. Lakhani, and C. Riedl. 2016. "Looking Across and Looking Beyond the Knowledge Frontier: Intellectual Distance, Novelty, and Resource Allocation in Science." *Management Science* 62 (10): 2765–2783. doi:10.1287/mnsc.2015.2285.

Braun, R., and J. Starkbaum. 2023. "Stakeholders in Research and Innovation: Towards Responsible Governance." In *Putting Responsible Research and Innovation into Practice: A Multi-Stakeholder Approach*, edited by V. Blok, 229–247. Cham: Springer International Publishing.

Collingridge, D. 1980. *The Social Control of Technology*. London: Francis Pinter.

de Jouvenel, B. 1967. *The Art of Conjecture*. London: Weidenfeld & Nicolson.

Decker, M., N. Weinberger, B.-J. Krings, and J. Hirsch. 2017. "Imagined Technology Futures in Demand-Oriented Technology Assessment." *Journal of Responsible Innovation* 4 (2): 177–196. doi:10.1080/23299460.2017.1360720.

Derbyshire, J. 2017. "The Siren Call of Probability: Dangers Associated with Using Probability for Consideration of the Future." *Futures* 88: 43–54. doi:10.1016/j.futures.2017.03.011.

Derbyshire, J., and G. Wright. 2017. "Augmenting the Intuitive Logics Scenario Planning Method for a More Comprehensive Analysis of Causation." *International Journal of Forecasting* 33 (1): 254–266. doi:10.1016/j.ijforecast.2016.01.004.

Douglas, C. M. W., and D. Stemerding. 2014. "Challenges for the European Governance of Synthetic Biology for Human Health." *Life Sciences, Society and Policy* 10 (1): 6. doi:10.1186/s40504-014-0006-7.

Dupuy, J.-P., and A. Grinbaum. 2004. "Living with Uncertainty: Toward the Ongoing Normative Assessment of Nanotechnology." *Techné: Research in Philosophy and Technology* 8 (2): 4–25. doi:10.5840/techne2004822.

European Commission. 2013a. "Horizon 2020 — Responsible Research & Innovation." Accessed April 2, 2021. https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation.

European Commission. 2013b. Horizon 2020, Work Programme 2014–2015: 16. Science with and for Society, C(2013)8631 of 10 December 2013.

Fenton-O'Creevy, M., and D. Tuckett. 2022. "Selecting Futures: The Role of Conviction, Narratives, Ambivalence, and Constructive Doubt." *Futures & Foresight Science* 4 (3-4): e111. doi:10.1002/ffo2.111.

Fischer, N., and S. Dannenberg. 2021. "The Social Construction of Futures: Proposing Plausibility as a Semiotic Approach for Critical Futures Studies." *Futures* 129: 102729. doi:10.1016/j.futures.2021.102729.

Fisher, E. 2019. "Governing with Ambivalence: The Tentative Origins of Socio-Technical Integration." *Research Policy* 48 (5): 1138–1149. doi:10.1016/j.respol.2019.01.010.

Fricker, M. 2007. *Epistemic Injustice: Power and the Ethics of Knowing.* New York: Oxford University Press.

Grin, J., and A. Grunwald. 2000. *Vision Assessment: Shaping Technology in 21st Century Society. Towards a Repertoire for Technology Assessment.* Berlin: Springer.

Groves, C. 2007. "Technological Futures and Non-Reciprocal Responsibility." *The International Journal of the Humanities: Annual Review* 4 (2): 57–62. doi:10.18848/1447-9508/CGP/v04i02/41814.

Groves, C. 2013. "Horizons of Care: From Future Imaginaries to Responsible Research and Innovation." In *Shaping Emerging Technologies: Governance, Innovation, Discourse*, edited by K. Konrad, C. Coenen, A. Dijkstra, C. Milburn, and H. van Lente, 185–202. Amsterdam: IOS Press.

Grunwald, A. 2009. "Technology Assessment: Concepts and Methods." In *Philosophy of Technology and Engineering Sciences*, edited by A. Meijers, 1103–1146. Amsterdam: North-Holland.

Grunwald, A. 2014. "Modes of Orientation Provided by Futures Studies: Making Sense of Diversity and Divergence." *European Journal of Futures Research* 2 (1): 30. doi:10.1007/s40309-013-0030-5.

Grunwald, A. 2019. "The Inherently Democratic Nature of Technology Assessment." *Science and Public Policy* 46 (5): 702–709. doi:10.1093/scipol/scz023.

Grunwald, A. 2020. "The Objects of Technology Assessment. Hermeneutic Extension of Consequentialist Reasoning." *Journal of Responsible Innovation* 7 (1): 96–112. doi:10.1080/23299460.2019.1647086.

Gudowsky, N., and M. Sotoudeh. 2017. "Into Blue Skies—A Transdisciplinary Foresight and Co-Creation Method for Adding Robustness to Visioneering." *NanoEthics* 11 (1): 93–106. doi:10.1007/s11569-017-0284-7.

Guston, D. H. 2013. ""Daddy, Can I Have a Puddle Gator?": Creativity, Anticipation, and Responsible Innovation." In *Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society*, edited by R. Owen, J. R. Bessant, and M. Heintz, 109–118. Chichester: Wiley.

Guston, D. H. 2014. "Understanding 'Anticipatory Governance'." *Social Studies of Science* 44 (2): 218–242. doi:10.1177/0306312713508669.

Guston, D. H., and D. Sarewitz. 2002. "Real-Time Technology Assessment." *Technology in Society* 24 (1-2): 93–109. doi:10.1016/S0160-791X(01)00047-1.

Irwin, A., T. E. Jensen, and K. E. Jones. 2013. "The Good, the Bad and the Perfect: Criticizing Engagement Practice." *Social Studies of Science* 43 (1): 118–135. doi:10.1177/0306312712462461.

Jasanoff, S. 2020. "Imagined Worlds: The Politics of Future-Making in the Twenty-First Century." In *The Politics and Science of Prevision: Governing and Probing the Future*, edited by A. Wenger, U. Jasper, and M. Dunn Cavelty, 27–44. London: Routledge.

Jonas, H. 1984. *The Imperative of Responsibility: In Search of an Ethics for the Technological Age*. Chicago, IL: University of Chicago Press.

Karinen, R., and D. H. Guston. 2009. "Toward Anticipatory Governance: The Experience with Nanotechnology." In *Governing Future Technologies: Nanotechnology and the Rise of an Assessment Regime*, edited by M. Kaiser, M. Kurath, S. Maasen, and C. Rehmann-Sutter, 217–232. Dordrecht: Springer.

Kera, D. R. 2020. "Anticipatory Policy as a Design Challenge: Experiments with Stakeholders Engagement in Blockchain and Distributed Ledger Technologies (BDLTs)." In *Blockchain and Applications. BLOCKCHAIN 2019. Advances in Intelligent Systems and Computing*, edited by J. Prieto, A. K. Das, S. Ferretti, A. Pinto, and J. M. Corchado, 87–92. Cham: Springer.

Kuhlmann, S., P. Stegmaier, and K. Konrad. 2019. "The Tentative Governance of Emerging Science and Technology—A Conceptual Introduction." *Research Policy* 48 (5): 1091–1097. doi:10.1016/j.respol.2019.01.006.

Lehoux, P., F. A. Miller, and B. Williams-Jones. 2020. "Anticipatory Governance and Moral Imagination: Methodological Insights from a Scenario-Based Public Deliberation Study." *Technological Forecasting and Social Change* 151: 119800. doi:10.1016/j.techfore.2019.119800.

Lucivero, F. 2016. "Scenarios as "Grounded Explorations". Designing Tools for Discussing the Desirability of Emerging Technologies." In *Ethical Assessments of Emerging Technologies: Appraising the Moral Plausibility of Technological Visions*, 155–190. Cham: Springer.

Macnaghten, P. 2021. "Towards an Anticipatory Public Engagement Methodology: Deliberative Experiments in the Assembly of Possible Worlds Using Focus Groups." *Qualitative Research* 21 (1): 3–19. doi:10.1177/1468794120919096.

Mann, C. 2015. "Strategies for Sustainable Policy Design: Constructive Assessment of Biodiversity Offsets and Banking." *Ecosystem Services* 16: 266–274. doi:10.1016/j.ecoser.2015.07.001.

Miller, R., and R. Sandford. 2019. "Futures Literacy: The Capacity to Diversify Conscious Human Anticipation." In *Handbook of Anticipation: Theoretical and Applied Aspects of the Use of Future in Decision Making*, edited by R. Poli, 73–91. Cham: Springer.

Mody, C. C. M. 2004. "Small, but Determined: Technological Determinism in Nanoscience." *HYLE – International Journal for Philosophy of Chemistry* 10 (2): 99–128.

Nordmann, A. 2007. "If and Then: A Critique of Speculative NanoEthics." *NanoEthics* 1 (1): 31–46. doi:10.1007/s11569-007-0007-6.

Nordmann, A. 2014. "Responsible Innovation, the Art and Craft of Anticipation." *Journal of Responsible Innovation* 1 (1): 87–98. doi:10.1080/23299460.2014.882064.

Owen, R., P. Macnaghten, and J. Stilgoe. 2012. "Responsible Research and Innovation: From Science in Society to Science for Society, with Society." *Science and Public Policy* 39 (6): 751–760. doi:10.1093/scipol/scs093.

Owen, R., and M. Pansera. 2019. "Responsible Innovation and Responsible Research and Innovation." In *Handbook on Science and Public Policy*, edited by D. Simon, S. Kuhlmann, J. Stamm, and W. Canzler, 26–48. Cheltenham: Edward Elgar.

Owen, R., J. Stilgoe, P. Macnaghten, M. Gorman, E. Fisher, and D. H. Guston. 2013. "A Framework for Responsible Innovation." In *Responsible Innovation*, edited by R. Owen, J. R. Bessant, and M. Heintz, 27–50. Chichester: Wiley.

Popa, E. O., and V. Blok. 2022. "Conspiracism as a Litmus Test for Responsible Innovation." In *Values for a Post-Pandemic Future*, edited by M. J. Dennis, G. Ishmaev, S. Umbrello, and J. van den Hoven, 111–128. Cham: Springer.

Popper, R. 2008. "Foresight Methodology." In *The Handbook of Technology Foresight: Concepts and Practice*, edited by L. Georghiou, J. Cassingena Harper, M. Keenan, I. Miles, and R. Popper, 44–88. Cheltenham: Edward Elgar.

Ramírez, R., and C. Selin. 2014. "Plausibility and Probability in Scenario Planning." *Foresight* 16 (1): 54–74. doi:10.1108/FS-08-2012-0061.

Repo, P., and K. Matschoss. 2019. "Considering Expert Takeovers in Citizen Involvement Processes." *Journal of Responsible Innovation* 6 (2): 119–142. doi:10.1080/23299460.2019.1568145.

Rip, A. 2016. "The Clothes of the Emperor. An Essay on RRI in and Around Brussels." *Journal of Responsible Innovation* 3 (3): 290–304. doi:10.1080/23299460.2016.1255701.

Rip, A., T. J. Misa, and J. Schot. 1995. *Managing Technology in Society: The Approach of Constructive Technology Assessment*. Edited by T.J. Misa and J. Schot. London: Pinter Publishers.

Rip, A., and D. K. R. Robinson. 2013. "Constructive Technology Assessment and the Methodology of Insertion." In *Early Engagement and New Technologies: Opening Up the Laboratory*, edited by N. Doorn, D. Schuurbiers, I. van de Poel, and M. E. Gorman, 37–53. Dordrecht: Springer.

Rip, A., and H. te Kulve. 2008. "Constructive Technology Assessment and Socio-Technical Scenarios." In *The Yearbook of Nanotechnology in Society, Volume I: Presenting Futures*, edited by E. Fisher, C. Selin, and J. M. Wetmore, 49–70. Dordrecht: Springer.

Robinson, D. K. R. 2009. "Co-Evolutionary Scenarios: An Application to Prospecting Futures of the Responsible Development of Nanotechnology." *Technological Forecasting and Social Change* 76 (9): 1222–1239. doi:10.1016/j.techfore.2009.07.015.

Sadowski, J., and D. H. Guston. 2016. "'You Caught Me off Guard': Probing the Futures of Complex Engineered Nanomaterials." *Journal of Nanoparticle Research* 18 (7): 208. doi:10.1007/s11051-016-3485-z.

Sardar, Z. 2010. "The Namesake: Futures; Futures Studies; Futurology; Futuristic; Foresight—What's in a Name?" *Futures* 42 (3): 177–184. doi:10.1016/j.futures.2009.11.001.

Sarewitz, D. R., R. A. Pielke, and R. Byerly. 2000. *Prediction: Science, Decision Making, and the Future of Nature*. Washington, DC: Island Press.

Schneider, C., M. Roßmann, A. Lösch, and A. Grunwald. 2021. "Transformative Vision Assessment and 3-D Printing Futures: A New Approach of Technology Assessment to Address Grand Societal Challenges." *IEEE Transactions on Engineering Management*, 1–10. doi:10.1109/TEM.2021.3129834.

Schwarz-Plaschg, C. 2018a. "Nanotechnology is Like … The Rhetorical Roles of Analogies in Public Engagement." *Public Understanding of Science* 27 (2): 153–167. doi:10.1177/0963662516655686.

Schwarz-Plaschg, C. 2018b. "The Power of Analogies for Imagining and Governing Emerging Technologies." *NanoEthics* 12 (2): 139–153. doi:10.1007/s11569-018-0315-z.

Selin, C. 2006. "Time Matters: Temporal Harmony and Dissonance in Nanotechnology Networks." *Time & Society* 15 (1): 121–139. doi:10.1177/0961463X06061786.

Selin, C. 2011. "Negotiating Plausibility: Intervening in the Future of Nanotechnology." *Science and Engineering Ethics* 17 (4): 723–737. doi:10.1007/s11948-011-9315-x.

Selin, C. 2014. "On not Forgetting Futures." *Journal of Responsible Innovation* 1 (1): 103–108. doi:10.1080/23299460.2014.884378.

Selin, C., and Â. Guimaraes Pereira. 2013. "Pursuing Plausibility." *International Journal of Foresight and Innovation Policy* 9 (2/3/4): 93–109. doi:10.1504/IJFIP.2013.058616.

Sotoudeh, M., and N. Gudowsky. 2018. "Participatory Foresight for Technology Assessment. Towards an Evaluation Approach for Knowledge Co-Creation." *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis* 27 (2): 53–59. doi:10.14512/tatup.27.2.53.

Stemerding, D., W. Betten, V. Rerimassie, Z. Robaey, and F. Kupper. 2019. "Future Making and Responsible Governance of Innovation in Synthetic Biology." *Futures* 109: 213–226. doi:10.1016/j.futures.2018.11.005.

Stilgoe, J., R. Owen, and P. Macnaghten. 2013. "Developing a Framework for Responsible Innovation." *Research Policy* 42 (9): 1568–1580. doi:10.1016/j.respol.2013.05.008.

Swierstra, T., D. Stemerding, and M. Boenink. 2009. "Exploring Techno-Moral Change: The Case of the ObesityPill." In *Evaluating New Technologies: Methodological Problems for the Ethical Assessment of Technology Developments*, edited by P. Sollie, and M. Düwell, 119–138. Dordrecht: Springer.

Swierstra, T., and H. te Molder. 2012. "Risk and Soft Impacts." In *Handbook of Risk Theory: Epistemology, Decision Theory, Ethics, and Social Implications of Risk*, edited by S. Roeser, R. Hillerbrand, P. Sandin, and M. Peterson, 1049–1066. Dordrecht: Springer.

Urueña, S. 2019. "Understanding "Plausibility": A Relational Approach to the Anticipatory Heuristics of Future Scenarios." *Futures* 111: 15–25. doi:10.1016/j.futures.2019.05.002.

Urueña, S. 2021. "Responsibility through Anticipation? The 'Future Talk' and the Quest for Plausibility in the Governance of Emerging Technologies." *NanoEthics* 15 (3): 271–302. doi:10.1007/s11569-021-00408-5.

Urueña, S. 2022. "Anticipation and Modal Power: Opening up and Closing Down the Momentum of Sociotechnical Systems." *Social Studies of Science* 52 (5): 783–805. doi:10.1177/030631272221111469.

Urueña, S., H. Rodríguez, and A. Ibarra. 2021. "Foresight and Responsible Innovation: Openness and Closure in Anticipatory Heuristics." *Futures* 134: 102852. doi:10.1016/j.futures.2021.102852.

van der Burg, S. 2009a. "Imagining the Future of Photoacoustic Mammography." *Science and Engineering Ethics* 15 (1): 97–110. doi:10.1007/s11948-008-9079-0.

van der Burg, S. 2009b. "Taking the "Soft Impacts" of Technology into Account: Broadening the Discourse in Research Practice." *Social Epistemology* 23 (3-4): 301–316. doi:10.1080/02691720903364191.

van der Burg, S. 2014. "On the Hermeneutic Need for Future Anticipation." *Journal of Responsible Innovation* 1 (1): 99–102. doi:10.1080/23299460.2014.882556.

von Schomberg, R. 2012. "Prospects for Technology Assessment in a Framework of Responsible Research and Innovation." In *Technikfolgen abschätzen lehren: Bildungspotenziale transdisziplinärer Methoden*, edited by M. Dusseldorp, and R. Beecroft, 39–61. Wiesbaden: VS Verlag für Sozialwissenschaften.

von Schomberg, R. 2013. "A Vision of Responsible Research and Innovation." In *Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society*, edited by R. Owen, J. R. Bessant, and M. Heintz, 51–74. Chichester: Wiley.

von Schomberg, R. 2014. "The Quest for the 'Right' Impacts of Science and Technology: A Framework for Responsible Research and Innovation." In *Responsible Innovation 1: Innovative Solutions for Global Issues*, edited by J. van den Hoven, N. Doorn, T. Swierstra, B.-J. Koops, and H. Romijn, 33–50. Dordrecht: Springer.

Warnke, P., and G. Heimeriks. 2008. "Technology Foresight as Innovation Policy Instrument: Learning from Science and Technology Studies." In *Future-Oriented Technology Analysis: Strategic Intelligence for an Innovative Economy*, edited by C. Cagnin, M. Keenan, R. Johnston, F. Scapolo, and R. Barré, 71–87. Berlin: Springer.

Withycombe Keeler, L., M. J. Bernstein, and C. Selin. 2019. "Intervening through Futures for Sustainable Presents: Scenarios, Sustainability, and Responsible Research and Innovation." In *Socio-Technical Futures Shaping the Present. Empirical Examples and Analytical Challenges*, edited by A. Lösch, A. Grunwald, M. Meister, and I. Schulz-Schaeffer, 255–282. Wiesbaden: Springer VS.

Zimmer-Merkle, S., and T. Fleischer. 2017. "Eclectic, Random, Intuitive? Technology Assessment, RRI, and Their Use of History." *Journal of Responsible Innovation* 4 (2): 217–233. doi:10.1080/23299460.2017.1338105.