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Anticipation and its degrees of critical-reflective radicality: opening up the affordances of engaging with futures to problematize STI

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ABSTRACT

Anticipation is increasingly recognized as a valuable dimension for promoting more responsible STI practices. Various normative frameworks acknowledge anticipation as a means to enable critique and/or reflection. However, the degrees of critique and reflection that anticipation can or should enable have remained under-researched. By exploring the critical-reflective affordances that anticipation could offer for problematizing STIs in the present, this article aims to advance the theoretical development of anticipation as a dimension for promoting more responsible STIs. The article suggests that the potential critical-reflective radicality of anticipation is modulated by the critical-reflective spaces of problematization and/or scrutiny afforded by the normative frameworks in which anticipation is interpreted and for which it is enacted. Against this background, the article provides some tentative variables for assessing these critical-reflective affordances and specifies the roles that different modes of anticipation might play in opening up distinct, interconnected aspects of STI to problematization and/or scrutiny.

Introduction

The last three decades have seen significant innovations in the development of normative frameworks and approaches to science, technology, and innovation (STI). Normative frameworks focusing on STI (hereafter 'STI normative frameworks') refer to a more or less explicitly itemized and systematically articulated set of guidelines, rules, capacities, or principles that prescribe how STI should be scrutinized, problematized, evaluated, and/or co-produced in order to practically increase the likelihood of more 'responsible' or 'better' STI development. STI normative frameworks are thus concerned with establishing criteria for shaping the dynamics of STI governance following their respective visions of ideal STI co-evolutions.

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STI normative frameworks that have received prominent academic and institutional attention include Anticipatory Governance (AG) (Barben et al. 2008; Foley, Guston, and Sarewitz 2018; Guston 2014), Responsible Research and Innovation (RRI) (European Commission 2013; von Schomberg 2013, 2014), Responsible Innovation (RI) (Stilgoe, Owen, and Macnaghten 2013), and recent formulations of Technology Assessment (TA) (Bechtold, Fuchs, and Gudowsky 2017; Grunwald 2019a; Lösch et al. 2019a). While these frameworks have their own distinctive features, they share common historical roots (e.g. Science and Technology Studies, diverse modes of TA, environmental studies) (e.g. Rip, Misa, and Schot 1995; Sarewitz 2011) and have been constituted through processes of mutual influence, overlap, inspiration, and critique (see Karinen and Guston 2009; Owen and Pansera 2019; Owen et al. 2013; van Lente, Swierstra, and Joly 2017).

Indeed, these frameworks share at least four common characteristics:

(i) The concept of responsibility in these frameworks revolves primarily around the degree of *social responsiveness* of STIs. The level of responsibility is determined by the extent to which STI aligns with the interests and expectations of society. As such, these frameworks emphasize the need for 'engagement' (AG) (Barben et al. 2008), 'inclusion' (RRI and RI) (Owen, Macnaghten, and Stilgoe 2012; Stilgoe, Owen, and Macnaghten 2013; von Schomberg 2013), and 'democratization' (TA) (Grunwald 2019a). Building on previous proposals that aim to foster the development of improved technologies within better societies (Rip 2006; Rip, Misa, and Schot 1995), the central idea is to enhance the socio-political legitimacy of STI projects through processes of socio-technical integration (Fisher 2019) and mutual learning from diverse perspectives and visions (van Oudheusden and Shelley-Egan 2021).

(ii) The frameworks adhere to proceduralism by presenting specific requirements that STI *processes* should seek to satisfy (see Pellé 2016). These requirements are defined as broad 'capacities' (Barben et al. 2008; Guston 2013; Selin et al. 2017), or as an assembled set of deliberative conditions (European Commission 2013; von Schomberg 2013, 2014) or 'dimensions' (Grunwald 2019a, 703; 2019b, 92–96; Stilgoe, Owen, and Macnaghten 2013, 1570–1574).

(iii) AG, RRI, RI, and TA have an early interventive character. They actively promote socio-epistemic practices from the early stages of research and development that aim to reinforce and enact their respective procedural conditions, dimensions, or capabilities.

(iv) They recognize 'anticipation' as a crucial dimension for addressing (rather than *resolving*) Collingridge's dilemma (Collingridge 1980).[1] Anticipation is meant to be enacted through non-predictive engagements with futures (e.g. foresight practices), and it is intended to serve a variety of purposes, including 'providing orientation' (Grunwald 2019a), 'building reflexivity' (Barben et al. 2008, 986), or challenging the status quo (Withycombe Keeler, Bernstein, and Selin 2019).

Although anticipation is an important dimension in these and other STI normative frameworks (e.g. Brey 2012; Brey et al. 2021), it remains under-theorized within their

associated academic circles. As Guston (2013, 110) diagnoses, 'there is less conceptual development around anticipation, and even poorer intuitions.' Currently, multiple interpretive and operational understandings of anticipation coexist (Pansera and Owen 2020), leading to diverse perspectives on its necessity and potential value in promoting more responsible STIs. While some question the necessity of anticipation (e.g. van de Poel 2016) and/or highlight potential counterproductive aspects of engaging with futures (e.g. Nordmann 2014), others defend its useful reflexive heuristics (e.g. Grunwald 2010; Selin 2014) or advocate for its 'amplification' (e.g. Lösch et al. 2019b; Nelson et al. 2022). Yet, there is still a lack of specificity in the literature regarding the meanings and challenges that anticipation can or should tackle and the reflective and critical scope that anticipatory practices can or should acquire in the face of current socio-material and political (anticipatory) dynamics (Macnaghten 2021).

This article aims to advance the theoretical development of anticipation as a dimension for promoting more responsible STIs by exploring the critical-reflective affordances that anticipation might theoretically offer for problematizing STIs in the present. The article argues that the potential critical-reflective radicality of anticipation is modulated by the spaces of critique and/or reflection afforded by the STI normative framework in which it is interpreted and for which it is enacted. Against this background, the article provides some tentative variables for assessing these critical-reflective affordances and specifies the roles that different modes of anticipation might play in opening up different aspects of STI to problematization and/or scrutiny.

The growing literature on recent STI normative frameworks that integrate an anticipatory dimension encompasses diverse objectives. Some literature aims to define, or review, the rationale behind each framework and establish their corresponding capacities, deliberative conditions, or normative procedural principles (e.g. Barben et al. 2008; Burget, Bardone, and Pedaste 2017; Grunwald 2019a; Stilgoe, Owen, and Macnaghten 2013; von Schomberg 2013). Other literature focuses on frameworks such as RRI and RI, delving conceptually into their normative foundations and underlying modes of moral reasoning (Pellé 2016) or scrutinizing and revising their underlying understanding of values (Boenink and Kudina 2020). Other more empirically oriented publications present practical interventions operationalizing (anticipatory mechanisms for) these frameworks (e.g. Betten et al. 2018; Lehoux, Miller, and Williams-Jones 2020; Schneider et al. 2023; Schuijff and Dijkstra 2020; Selin 2011), discuss how the meanings of frameworks are contextually reconfigured and negotiated (e.g. Doezema et al. 2019; Pansera and Owen 2020; Vasen 2017), or highlight the instrumentalization and systemic challenges they face (e.g. Rodríguez, Eizagirre, and Ibarra 2019; Tabarés et al. 2022). In addition, Conley (2020) demonstrates that certain informal or formal governance practices and capacities, although not enacted or informed by STI frameworks such as AG and RI, may share their spirit of 'open[ing] up socio-technical contracts to greater scrutiny' (Conley 2020, 511). Despite these and other important developments, there is still a lack of comprehensive analysis of (i) the gradients that STI normative frameworks and related practices theoretically and practically afford with respect to such 'openings' and 'scrutinizations,' (ii) how to qualitatively identify these radicalities, and (iii) how these gradients affect or shape the anticipatory dimension. This article aims to address this gap from a predominantly theoretical–conceptual perspective. Nevertheless, its main conclusions have practical implications for real-world experiences and empirical

approaches aimed at enacting critique and/or reflection, whilst also remaining open to further enrichment or reformulation by these more practical and empirical orientations. In addressing this research gap, the article provides insights into, and encourages a problematization of, the roles that STI normative frameworks and different modes of engagements with futures play in affording and enabling different degrees of anticipatory critique and/or reflection.

The argument develops as follows. First, the paper provides a conceptual foundation for the phenomenon of anticipation. These foundations show that STI governance has typically been 'anticipatory' in heterogeneous ways. Anticipation has been practiced in different forms, in terms of engagements with futures and in support of different goals. However, recent STI normative frameworks such as AG, RRI, RI, and TA understand and enact anticipation primarily as a means of promoting critique and/or reflection (section 2). The article then addresses the potential critical-reflective affordances of anticipation. It does so by (i) diagnosing that these critical-reflective affordances appear to be subordinate to the critical-reflective affordances of STI problematization that each normative framework invokes, and (ii) offering some tentative variables for identifying the extensional radicality of these critical-reflective affordances (section 3). The following sections address the theoretical relations between the forms of engagement with futures that anticipation can articulate and one of the variables that might be used to delineate the critical-reflective extensionality of STI normative frameworks and their anticipatory practices: the aspects of STI that are invited to be problematized (section 4). The article then delves into the methodological and practical implications of the preceding findings. It suggests that initiating and articulating anticipatory exercises *with* and *in* critical-hermeneutic engagements with futures may afford more radically critical-reflective anticipatory capabilities and actions (section 5). The article ends with a series of concluding remarks.

Setting the stage: anticipation and its heterogeneity in STI governance

Before analyzing the critical-reflective affordances of anticipation for promoting better and more responsible STIs, it is crucial to establish a basic conceptual understanding of 'anticipation.' Anticipation and Futures Studies (A&FS) constitute a cluster of perspectives and fields of inquiry that explore and reflect on the different ways in which 'futures' are mobilized and used (see Bell 2003; Dator 2019; Masini 2006; Sardar 2010; Slaughter 1998). The concept of anticipation, as commonly used in A&FS, can provide an initial basis for further elucidating this socio-epistemic practice's meaning(s) and significance.

Departing from a basic concept of anticipation: anticipation and futures studies

Anticipation is conceptualized in A&FS as *any action or capacity enacted or informed in the present through engagements with representations or models that appeal to futures* (see Poli 2015, 2017, 2019b). The representations of the future and the types of engagements with these that enact or inform the action can vary in nature, forming different modes of anticipation (Muiderman et al. 2020; Urueña 2021). The following actions are consistent with this basic definition of anticipation and can therefore be taken as non-restrictive examples of different ways of performing anticipation:

Example 1. Jessica sees on the weather forecast that it is meant to be a rainy day, so she grabs an umbrella before leaving home.

Example 2. Microsoft wants to increase its capital and, assuming the promising applications and future benefits that artificial intelligence will have, decides to invest billions of dollars in the artificial intelligence lab OpenAI.

Example 3. The ChatGPT team imagines various plausible misuses that future users could make of their innovation and, based on this, introduces limitations on the information it could provide.

Example 4. Different societal actors critically evaluate the assumptions underlying the visions and promises of nanotechnology and, on this basis, develop and/or strengthen their futures literacy and deflate the speculative and performative character of these visions and promises when evaluating the desirability of nano.

These examples show that anticipation encompasses a wide range of actions and capacities beyond those enacted through engagements with a single representation of the future that is constructed and approximated as denoting what will probably be the case (compare Example 1 with the others). Anticipation encompasses actions and capabilities enacted by human agents (Bryant and Knight 2019; Hölscher 2018; Oettingen et al. 2018; Seligman et al. 2016) as well as nonhuman entities such as animals (e.g. van den Bos 2019), plants (e.g. Novoplansky 2016), robotic systems (e.g. Winfield and Hafner 2019), and socio-technical systems (see Beckert and Bronk 2018; Mische 2009, 2014). Given the scope of this article, the following discussion focuses on anticipations undertaken by human and social actors in the context of STI governance to actively enhance the (socio-political) robustness of STI development.

STI governance has always been anticipatory: de facto and interventive anticipations

STI governance is an inherently future-oriented activity and, as a result, many of its complex set of distributed constitutive capabilities, activities, and decisions are driven by formal or informal representations of potential futures. Recent literature in Science and Technology Studies (STS) highlights that STI dynamics are enmeshed in, and therefore shaped by, complex anticipatory assemblages (see Alvial-Palavicino 2015; Konrad et al. 2016).

On the one hand, STIs have been shown to be embedded in anticipatory assemblages that are constructed, shared, maintained, and contested in the present through the mobilization of promises (van Lente and Rip 1998), expectations (Borup et al. 2006; Konrad and Palavicino 2017; Selin 2007), visions (Schneider and Lösch 2019), and socio-technical imaginaries (Ballo 2015; Jasanoff and Kim 2015). These 'futures' shape the spaces of (im)plausibility and (un)desirability to which actors commit, enticing them to construct shared agendas and act in certain directions (at the expense of others) (Roßmann 2021; Urueña 2022). Through the mobilization of temporality, these 'futures' are shown to play a crucial role in shaping and influencing the ongoing distributed negotiations that shape STI trajectories (Selin 2006).

On the other hand, the formal and methodical use of futures as a resource for promoting and informing *ex-ante* forms of STI governance has a long history. Early reports such as *Technological Trends and National Policy, Including the Social Implications of*

New Inventions (1937) (US National Resources Committee 1937) and *Technological Fore-casting in Perspective* (1967) (Jantsch 1967) are examples of systematic efforts to examine and support governance mechanisms that can strictly be considered 'anticipatory.' Specifically, they proposed to inform decisions about STI on the basis of probabilistic forecasting models which attempt to eliminate uncertainty about what the future holds (see Coates, Mahaffie, and Hines 1994; Ported 1995). The main goal was to 'foresee as clearly as may be possible, the nature and probable impact of a rapidly growing technology' (Jantsch 1967, 11), so that appropriate measures could be taken in advance (compare with Example 1). Some early approaches and practices of TA, such as prospective and governmental or parliamentary TA, often categorized as 'classical TA,'[2] are also consistent with this rationale:

> Ideally the concept of TA is that it should *forecast, at least on a probabilistic basis*, the full spectrum of possible consequences of technological advance, leaving to the political process the actual choice among the alternative policies in the light of the best available knowledge of their likely consequences (Brooks 1976, 20; emphasis added).

The enactment of anticipations based on probabilistic-forecast future models remains operational in certain contexts of STI governance, such as risk assessment practices (e.g. Money, Reckhow, and Wiesner 2012; Wiesner and Bottero 2011). However, it has been widely criticized in STS-related circles (e.g. Jasanoff 2003; Sarewitz, Pielke, and Byerly 2000; York and Clark 2007) and AF&S (e.g. Derbyshire 2017; Sardar 2010).

On the one hand, any attempt to base action on epistemically robust predictions has been shown to be illusory because of the complex and unruly nature of the co-evolutionary dynamics between STI and society, especially in the early stages of STI development. Collingridge's (1980) dilemma highlights the inherent tension between the comparatively malleable nature of STIs in their early stages of development and the epistemically precarious conditions that accompany these phases. On the other hand, anticipations based on probabilistic forecasting models are accused of not allowing for a comprehensive problematization of STIs (or even of being counterproductive to it). By 'reassuring us that all futures are measurable, and hence calculable and manageable' (Jasanoff 2018, 13), forecast-based forms of enacting anticipation are seen as akin to reproducing 'technological hubris' (Jasanoff 2003). This means that the contingencies, normative and ontic openness and novelty, unknowability and uncertainty inherent in STI co-production processes are overlooked by these narrow forms of enacting anticipation. They fail to make visible and address key concerns such as problem framings, vulnerability, distribution, the role of emotions and desires, and the moral and political dimensions of STI future-making practices (Jasanoff 2003, 2016; Wyborn et al. 2020). Due to their inability to afford reflection and critique, such forecast-based forms of 'anticipatory' governance and decision-making have been diagnosed as instrumental in perpetuating current modes of future-making, thereby preserving the status quo (see Derbyshire 2017; Miles 1975; Ramírez and Selin 2014; Selin 2011; Selin and Pereira 2013).

However, the recognition of these difficulties, pitfalls, and limitations has not diminished the intention to use and exploit 'futures.' Rather, it has stimulated the exploration of alternative ways of engaging with and exploiting future temporality.

> [T]he failure to predict the 1973 'oil-shock' led to considerable scepticism concerning the validity and utility of forecasting. (…) Anticipation or foresight involves an explicit

recognition that the choices made today can shape or create the future, and that there is little point in making deterministic predictions in spheres (including science and technology) where social and political processes exercise a major influence. There has consequently been a move away from forecasting and prediction towards activities variously labelled as 'outlook', 'foresight', 'issues management' and 'la prospective' (Irvine and Martin 1989).[3]

In contrast to forecasting practices, foresight practices maintain a more open and exploratory attitude toward the multiple possibilities for action available in the present. They take a deflationary approach to the notion of knowing or predicting the future, acknowledging the presence of uncertainty and embracing the potential for novelty and unexpected events (Bell 2003; de Jouvenel 1967). However, this pluralistic and deflationary understanding of engaging with 'futures' (in the *plural*) takes different forms. Foresight is an umbrella term that encompasses different approaches to constructing, engaging with, and using 'futures.' These approaches can range from qualitative to quantitative, draw on expert knowledge or incorporate multiple perspectives, and focus on creativity or evidence-based methods (see Popper 2008). In addition, these exercises can be grounded on different core epistemological and ontological assumptions and can be pragmatically oriented to achieve different goals (e.g. strategic planning, exploring plausible and desirable futures, or fostering critical analysis) (see Gidley 2017).[4]

For example, in the context of STI, anticipations informed by foresight practices have been and continue to be used by STI institutions and firms to identify potential 'winning' market niches and 'future-proof' priorities worth investing in (e.g. Irvine and Martin 1989; Martin and Johnston 1999; Rohrbeck and Gemunden 2009) (compare with Example 2). Moreover, STS scholars have also used foresight as a means to support and promote the visions embedded in their respective STI normative frameworks. This is the case, for example, with the use of socio-technical scenarios that explore alternative co-evolutions of STI and society in order to promote the social learning processes called for by Constructive TA (Rip and Kulve 2008; Robinson 2010) (compare with Example 3). Other foresight interventions aim to anticipatorily activate critique and/or reflection of dominant imaginaries and hegemonic visions circulating in the present (Grin and Grunwald 2000; Roelofsen et al. 2008; Schneider et al. 2023) (compare with Example 4).

The diversity of foresight exercises, their purposes, and the resulting anticipatory heuristics suggest that the deviation of foresight-based anticipations from the 'hubris' of forecast-based anticipations is not fixed or absolute (see Andersson 2018). Rather, this deviation varies in degrees, and in order to identify and evaluate these degrees, one must consider the *rationale* and *socio-epistemic dynamics* of each specific anticipatory technique and practice.

Toward a tentative characterization of the critical-reflective affordances of STI normative frameworks

The previous section illustrated that the governance of STI has typically been strictly 'anticipatory.' The future has long been used as a resource to guide the present of STI, both informally (through visions, expectations, and imaginaries) and formally (through forecasting and foresight). However, the uses of futures that have been used

formally to shape the governance of STI are diverse and serve different purposes. The different functions of futures reflect not only the heterogeneity of anticipation as a phenomenon but also the heterogeneity of the ambitions and cultures of opening up and closing down STI that underpin the uses of these futures. In other words, the different ways of understanding and performing 'anticipation' for shaping STI governance reflect and at the same time constitute the coexisting positionings that configure the politics *of* and *with* anticipation (Jasanoff 2020).

The fact that the different modes of enacting anticipation are tied to different goals and understandings of how to shape STI governance leads us to recognize the following: *The theoretical critical-reflective affordances that anticipation can and seeks to enable are* ex-ante *modulated by the goals and critical-reflective affordances of the normative frameworks that anticipation seeks to serve.*[5] The potential actions and functionalities that an artifact offers through its particular design are commonly referred to as 'affordances.' Affordances are a crucial aspect of the material and agential power of artifacts. They define not only what artifacts can do but also how they do it (see Davis 2020). While the focus is often on the affordances of material artifacts, such as technological artifacts or socio-technical systems (Faraj and Azad 2012), the concept of 'affordance' can also be applied to conceptual and discursive artifacts, such as STI normative approaches and frameworks. Similar to how a speed bump encourages drivers to slow down, thereby shaping socio-technical networks that lead to reduced traffic speeds (Latour 1992), STI normative frameworks also encourage specific acts of scrutiny and/or problematizations of STIs. Depending on their respective objectives, axiologies, and normative anchorages, each STI normative framework affords (or does not afford) the scrutiny and/or problematization of certain aspects of STIs and in different modes. Thus, in exploring the meanings and roles of anticipation within current STI normative frameworks, it is essential to first consider how normative frameworks modulate both (i) the pragmatic meanings and orientations of anticipation, and thereby (ii) their theoretical and practical affordances for scrutinizing and problematizing STI. The following two subsections address these two issues, respectively.

The critical-reflective orientation of recent calls for 'anticipation'

As noted in the introduction, STI normative frameworks are concerned with establishing criteria for shaping the dynamics of STI governance in accordance with their respective visions of ideal STI co-evolutions. The pragmatic orientation and modes of enacting anticipation will depend on the visions embedded in each concrete framework that calls for 'anticipation.' While this implies that anticipation will inevitably be heterogeneous, an examination of the various texts articulating and explaining the rationales of recent STI normative frameworks, such as AG, RRI, RI, and recent approaches to TA, reveals the existence of some commonalities (and differences) in the general pragmatic orientation that the uses of futures currently pursue. In particular, these texts contain both negative and positive characterizations of anticipation (see Table 1).

Negative characterizations provide information about the types of engagements with futures, and subsequent modes of articulating anticipation, for problematizing STI that normative frameworks reject as part of their 'valid' repertoire. For example, both AG and RI show a clear rejection of anticipations articulated on predictivist forms of engagement with futures (e.g. forecast-based modes of anticipation). Only TA mentions the

Table 1. Anticipation in AG, RRI, RI, and TA.

Normative Framework	Dimensions / Capacities	Negative characterizations	Positive characterizations	Examples of desired anticipatory heuristics	Examples of methods enacting anticipation
AG	**Foresight** Engagement Socio-technical integration Ensemblization	'is distinct from notion of predictive certainty' (Barben et al. 2008, 992); 'from an always-illusory capacity to predict' (Guston 2013, 114) 'does not suppose that we can look into the future as an 'it,' as an identifiable object' (Guston 2013, 115)	'comprises the ability of a variety of lay and expert stakeholders (…) 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) 'Anticipation implies an awareness of the co-production of sociotechnical knowledge and the importance of richly imagining sociotechnical alternatives that might inspire its use' (Barben et al. 2008, 992) 'It supposes that the future is an admixture of predetermined elements (path dependences, obdurate institutions, and the like) and critical uncertainties' (Guston 2013, 115)	'to enrich futures-in-the-making by *encouraging and developing reflexivity*' (Barben et al. 2008, 986) 'learn better how to survive in that 'undiscovered country' of the future' (Guston 2013, 111) 'can cause scientists and engineers to, *upon reflection*, alter the agendas and strategic vision of science-in-the-making' (Guston 2014, 229) 'amplifying the still, small voices less often heard in the innovation process' (Guston 2014, 229) 'will favor more socially beneficial choices – that is, choices that steer toward articulated public values' (Sarewitz 2011, 102)	Foresight (scenario workshops, science fiction prototyping)
RRI	**Broader foresight** and impact assessments Inclusive deliberation (normative anchor points derived from the European Treaty)	Should not be limited to 'market-benefits and risks' (von Schomberg 2013, 51)	Identify 'positive and negative impacts or, whenever possible, define desirable impacts of research and innovation both in terms of impact on consumers and communities' (von Schomberg 2012, 51)	'help us to overcome the often too narrowly conceived problem definition scientists implicitly work with' (von Schomberg 2012, 46) 'can reduce the human cost of trial and error and make advantage of a societal learning process of stakeholders and technical innovators. It creates a possibility for anticipatory governance. This will ultimately lead to products which are (more) societal robust' (von Schomberg 2012, 52)	TA toolkit, with emphasis on technology foresight (von Schomberg 2012, 46) 'broader foresight and impact assessments for new technologies' (von Schomberg 2013, 51)
RI					

(*Continued*)

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Table 1. Continued.

Normative Framework	Dimensions / Capacities	Negative characterizations	Positive characterizations	Examples of desired anticipatory heuristics	Examples of methods enacting anticipation
	Anticipation Inclusion Responsiveness Reflexivity (Care) (Deliberation)	'do not set out to predict' (Owen, Macnaghten, and Stilgoe 2012, 755) '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)	'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 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) 'describing and analyzing those intended and potentially unintended impacts that might arise, be these economic, social, environmental, or otherwise' (Owen et al. 2013, 38)	'serve to both open up and explore promissory narratives of expectation as well as other plausible pathways that may lead to other impacts: to prompt 'what if … ' questions' (Owen, Macnaghten, and Stilgoe 2012, 755) 'serve as a useful entry point for reflection on the purposes, promises, and possible impacts of innovation' (Owen et al. 2013, 38)	'foresight, technology assessment and scenario development' (Owen, Macnaghten, and Stilgoe 2012, 755) Horizon scanning, scenario planning, vision assessment (Stilgoe, Owen, and Macnaghten 2013, 1571)
TA	**Anticipation** Inclusion Complexity	*(Not found)*	'addresses the dimension of time when facing an open future' (Grunwald 2019a, 703)	'providing and assessing prospective knowledge' (Grunwald 2019a, 703) 'enhancing reflexivity over time' (Grunwald 2019a, 703)	TA toolkit, with emphasis on Vision Assessment (Hermeneutic TA)

possibility of basing anticipations on *prospective knowledge* (Grunwald 2019a, 703). However, Grunwald (2020, 97–99) recognizes the difficulties and potential pitfalls of using such a prospective approach with respect to new and emerging technologies. Indeed, he shares with AG, RRI, and RI an emphasis on the need to recognize contingency and the 'openness of the future,' and thus to be cautious about the potential closures and hubris that prospective ambitions embody and may generate.

In contrast, recent normative frameworks are consistent in triggering anticipation through foresight practices. This is because, as discussed in the previous section, foresight practices are considered more appropriate for recognizing the openness of the future, embracing uncertainty, ignorance, and multiple ways of knowing, and promoting capacity-building mechanisms for learning from experimental and (un)successful ongoing experiences. Specifically, the positive definitions of anticipation emphasize that foresight-based forms of anticipation aim to promote *reflection* and/or *reflexivity* within STI co-production processes. Moreover, this anticipatory activation of reflection and reflexivity is coupled with inclusivist ambitions (e.g. the inclusion of diverse voices and the articulation of public values within STI co-production processes). Enacting *critique* through anticipation is also considered. However, there is still less conceptual development of 'critique' (Smolka 2020, 1–3), and it is much less discursively prominent compared to the goals related to reflection or reflexivity (see Table 1).

The difference between the discursive emphasis on reflection or reflexivity and critique points to a first aspect to consider when assessing the gradations of problematization of STI afforded by normative frameworks and their associated anticipatory practices: Do normative frameworks and their associated anticipatory practices primarily promote reflection and reflexivity, or can/should they extend their scope to foster critique? As Grunwald (2019a, 703) notes, 'enhancing reflexivity is a rather abstract notion and has to be made more specific.' This is also true of enhancing reflection and critique.

The terms 'reflection,' 'reflexivity,' and 'critique' refer to distinct capacities and actions that offer different heuristics. Reflection involves actively scrutinizing a subject in order to cultivate awareness of (some of) its constitutive features (e.g. tacit assumptions, components, conditions, roles, and positioning in the world). Reflections can range from extrospective (when the object of reflection is external to the system performing the reflective action) to introspective (when the system performing the reflective action is both the subject and the object of reflection). 'Reflexivity' refers to introspective modes of reflection. An example of extrospective reflection would be when a group of science ethnographers examine the laboratory life of a group of nanoscientists and raise awareness of how the (non-)epistemic cultures and values of these nanoscientists shape their scientific practices. An example of introspective reflection would be when a group of science ethnographers scrutinize themselves and become self-aware of their own conditions, feelings, assumptions, roles, motives, and values and how these might affect their own research practices.

Promoting extrospective and introspective reflective practices and capacities among the actors involved in STI constitutive processes can contribute to an understanding of these processes and to a (self-)understanding of the roles and agencies these actors have within them. This, in turn, could serve the purpose of increasing transparency. However, simply scrutinizing the constituent features of a subject and the resulting (self-)awareness heuristics is insufficient to indicate potential paths for improvement or transformation. To broaden the scope of plausible and desirable futures, it is essential

not only to identify these constitutive features but also to problematize their current strengths and limitations and to challenge them with possible alternatives. The cultures and values of nanoscientists scrutinized by ethnographers, as well as the factors backing their ethnographic practices, can only be effectively refined or transformed if they are also, once identified or scrutinized, problematized. This problematization is the primary function of critique. Critique builds on reflection (whether extrospective or introspective), but reflection alone does not necessarily lead to critique.[6]

This is not to imply that critique alone can secure transformation. Rather, transformation requires that critique, and the resulting opening up of alternatives, lead to actions for change and that these actions become disruptive. Transformation requires disruptive actions, which often must confront resistance to change and socio-technical contexts that are prone to maintenance and closure dynamics (Stirling 2008). Moreover, I am not suggesting that interventive, anticipatory attempts focused solely on promoting extrospective or introspective reflections are unimportant or unnecessary. STI co-production processes that include certain forms of reflection are undoubtedly more desirable than those lacking it. The main point is rather that reflection and critique have distinct heuristics: Normative frameworks and their associated anticipatory practices aimed solely at fostering extrospective reflection or reflexivity may offer more conservative (or less radical) insights for illuminating alternative pathways of transformation than those that focus on or build upon critique. If normative frameworks for STI aim to actively shape the transformation of STI co-production processes through anticipatory interventive practices, then they must more explicitly extend their desiderata beyond the promotion of extrospective reflection or reflexivity. They should (i) more clearly emphasize in both their discourses and practices their focus on generating critique, and (ii) specify the scope that their critical problematizations are intended to achieve.

Identifying the extensional critical-reflective radicality of normative frameworks: toward some tentative variables

The previous subsection has shown how recent STI normative frameworks seek to activate anticipatory heuristics and capacities through inclusive foresight exercises. These heuristics and capacities are mainly oriented toward promoting reflection (whether extrospective or introspective) and/or critique. It was also noted that reflection and critique have different heuristic scopes: while reflection entails scrutiny and can produce (self-)awareness, critique entails problematization and can be useful in identifying possible needs and avenues for transformation. Thus, frameworks and anticipatory practices that encourage and build upon critique might offer more appropriate and radical heuristics for transforming current modes of STI co-production than those that are limited to shaping reflection.

This section delves into the varying levels of scrutiny and problematization of STI opened up by normative frameworks and their associated anticipatory practices. The first step involves recognizing that it is not enough to focus only on whether frameworks and their associated anticipatory practices operate within the realm of reflection or, more radically, within the realm of critique. It is also necessary to attend to the gradations that such forms of scrutiny (in the case of reflection) or problematizations (in the case of critique) acquire. The commitment to the anticipatory enactment of extrospective or introspective reflection or critique is still unaccompanied by specific criteria that help to assess

the breadth and depth of scrutiny or problematization of STI that normative frameworks and their associated anticipatory practices theoretically aim for or empirically achieve. The purpose of this subsection is to suggest some tentative criteria for assessing the critical-reflective affordances that normative frameworks theoretically afford and, derivatively, might encourage through their associated anticipatory practices.

These critical-reflective affordances can be assessed in terms of their breadth (extensional radicality gradients) and/or depth (intensional radicality gradients). The extensional critical-reflective radicality refers to the *extension* of the various spaces, aspects or dimensions of STI that the frameworks theoretically or practically entice to open up for scrutiny or problematization. Intensional critical-reflective radicality refers to the *depth* that such openings of STI acquire.

The following example illustrates the difference between extensive and intensive gradients. Suppose that we want to identify the gradations of reflection STI and/or critique offered by a guide to fine art analysis. After reading the guide, we find that it states that any scrutiny and/or critique of a painting should take into account the socio-historical context of the painting, the biography of the artist, the techniques used, the materials and pigments used, and so on. These criteria would define the extensive critical-reflective affordances of the guide: They would constitute the extensive aspects of paintings that the guide invites to scrutinize or problematize. The intensional affordances of the guide would depend on the elements mentioned for the treatment of each of the above extensive criteria (i.e. its depth). For example, it might indicate that in problematizing 'the techniques used to paint,' one might focus on brushwork, palette, blending and mixing styles, use of perspective, and so on. Depending on how comprehensive the guide's extensive and intensive criteria are, its affordances for scrutinizing and/or problematizing painting could be considered more or less rich or radical from an extensive/intensive perspective.[7]

Similar to the guide, the discourses, narratives, and practices through which the meanings of STI normative frameworks are constituted invite us to scrutinize or problematize STI under different critical-reflective gradients – either extensive or intensive – and thus allow for the opening of different breadths and depths of reflection and/or critique regarding STI. However, unlike the guide, normative frameworks do not always have their criteria clearly and/or explicitly formulated, nor are these criteria always static and intended to function in the same rigid manner as the example of the guide might suggest. On the one hand, the fact that extensive and intensive gradients are not always clearly or explicitly defined indicates that their identification may require complex hermeneutic work – as is the case with the identification of valuing processes (Boenink and Kudina 2020). While texts that aim to define the rationale of STI normative frameworks are typically more explicit and therefore demand less hermeneutic work, this work will be particularly challenging when assessing informal 'transductions' (see Doezema et al. 2019) and especially interventive practices. On the other hand, the fact that the criteria are not always static stems from the fact that normative frameworks are subject to ongoing dynamics of elaboration and reconfiguration. Normative frameworks are typically characterized and labeled in an abstract manner in texts that establish their corresponding defining capacities, deliberative conditions, or normative (procedural) principles (e.g. Barben et al. 2008; Stilgoe, Owen, and Macnaghten 2013).[8] Nevertheless, the specific meanings that these acquire within their overarching core identities are continuously being (re)shaped over space and time (Doezema et al. 2019). This implies that the extensive degrees of radicality of a particular STI normative framework

may vary depending on whether it is understood in the abstract or as it is contextually reconfigured and implemented. The term 'STI normative framework' in this context is thus intended to encompass both abstract conceptions and their practical, ongoing reconfigurations through 'transduction' practices in particular settings and interventive experiments. The following proposed variables can be used to assess the critical-reflective affordances of the derivatives of any process and practice of normative *framing* for STI, including those that constitute and underpin (anticipatory) interventive practices.

A comprehensive assessment of the critical-reflective affordances of STI normative frameworks and/or associated practices would require attending to both their extensive and intensive radicalities. The focus here, however, will be primarily on the identification of some tentative and non-exhaustive variables for identifying extensive radicalities (albeit some variables for identifying intensive radicalities will also be mentioned along the way). The rationale for focusing primarily on extensive gradients is related to their privileged position in terms of theoretical sequencing. As the example of the guide illustrates, intensive gradients take on meaning in relation to, or within, the spaces of scrutiny and/or problematization previously delineated by extensive gradients. Therefore, the need to identify and discuss extensive variables takes priority over intensive gradients. Future research could address both the refinement and expansion of the variables proposed here to identify extensive radicalities, as well as the further elaboration of potential variables to identify and assess intensive radicalities.

The extensive critical-reflective affordances that normative STI frameworks and their associated (anticipatory) practices can theoretically offer can be characterized by the interplay of at least four variables: (i) temporality, (ii) inclusivity, (iii) STI aspects problematized, and (iv) operational positioning in relation to STI practices (see Table 2). Each

Table 2. Tentative variables to identify the breadth of reflection and/or critique afforded by normative frameworks for STIs.

Extensive Radicality	Variables			
	Temporality	Inclusivity	STI aspects scrutinized / problematized	Operational positioning
Less radical	Ex-post	Experts • STEM • Social sciences, arts and humanities • Socio-technical integration	STI outcomes/impacts: • Negative impacts • Right impacts	External assessment (e.g. parliamentary TA)
	Ex-dure	Stakeholders	STI processes	Parallel assessment (e.g. ELSA/ELSI)
More radical	Ex-ante	'All' societal actors	STI purposes • Technical-functional purposes • Socio-political purposes and orders Underlying assumptions, values, and socio-material conditions reifying futures (e.g. problem definitions, visions, expectations, imaginaries, structures)	Socio-technical ensemblization (ingrained in STI co-production dynamics; capacity-building approaches to STI governance)

of these variables correlates with a key question regarding how STI normative frameworks and/or their associated anticipatory practices encourage the scrutiny or problematization of STIs. While these criteria could potentially be directly used to identify and evaluate the breadth of scrutiny and problematization facilitated by the anticipatory interventive practices associated with a normative framework, this paper advocates taking a preliminary step. It suggests applying these criteria to discern the breadth of reflection and/or critique afforded by the frameworks themselves (whether defined in abstract, or contextually and concretely reconfigured). The rationale behind this approach is that the intervening practices associated with normative frameworks are aimed at pursuing (to a greater or lesser extent) the normative ambitions of the specific (reconfigured) framework with which they are associated. Consequently, anticipatory interventive practices are likely to operate *within* the critical-reflective affordances provided by the concrete (reconfigured) normative framework they are intended to enact.[9]

(i) *Temporality*: When should the scrutiny and/or problematization of STIs take place?

STI normative frameworks can invite the enactment of reflection and/or critique of STI at different stages of development. They can invite and afford the scrutiny and/or problematization of an STI after it has been developed (*ex-post*), during its development (*ex-dure*), and/or from the very early stages of its development (*ex-dure*) (see Reijers et al. 2018; Schuijff and Dijkstra 2020). The breadth or extensive radicality of the scrutiny and/or problematization that each STI normative framework affords would depend on how many of these stages each normative framework cumulatively covers. For example, a normative framework that only proposes a kind of *ex-post* problematization of STIs can be considered to have a lower extensive radicality than others that *also* invite an *ex-dure* problematization. Normative frameworks that aim to cover the whole temporal spectrum by inviting a problematization of STIs in all their research and development phases (*ex-ante*, *ex-dure*, and *ex-post*) would be considered highly radical from the temporal variable. Some examples of the latter include AG, RRI, RI, and recent approaches of TA (Guston and Sarewitz 2002), as characterized in their recent foundational literature.

(ii) *Inclusivity*: Whose voices are involved in the process of scrutinizing and/or problematizing STIs?

Depending on the social actors and their respective knowledges, values, motivations, feelings, etc. that are considered legitimate to activate the scrutiny and/or problematization of STIs, the spaces of reflection and/or critique that a STI normative framework opens up can acquire different inclusivity gradients. For example, a normative framework might have a very limited inclusive radicality if it invites the problematization of STI to be enacted only by experts from science, technology, engineering, and mathematics (STEM) fields. The inclusive breadth could be expanded if it is enacted by experts from STEM and from the arts, social sciences, and humanities, or even more so if there is a call to problematize STI through socio-technical integration.

However, STI normative frameworks could go one step further in their extensive gradients of inclusivity if they include not only actors typically referred to as 'experts' but also (other) stakeholders (all those actors with interests at stake in relation to the STI in question). In turn, STI normative frameworks could present a greater gradient of inclusive radicality if they do not limit the inclusion of voices to those with interests at stake but extend it to all social actors (or, better said, if they consider all social actors as potential stakeholders, since all actors can be considered as co-inhabitants of the socio-technical systems maintained/modified/contested by STIs).

Of course, the breadth of the types of actors considered legitimate to scrutinize and/or problematize STIs should not be the only criterion; it should be considered in conjunction with intensive criteria. For example, it would be relevant to consider under what conditions and how the different voices, values, and needs are actually heard/silenced, recognized/ignored and/or supported/contested. Another important question in assessing the depth of the inclusiveness variable would be whether inclusivity acquires a binding effect or whether it is merely cosmetic in the service of domesticating STIs. The application of these intensive criteria of inclusivity becomes even more necessary in contexts where the inclusion of different actors acquires an ambivalent character, with a tendency toward instrumentalization (Rodríguez, Eizagirre, and Ibarra 2019).

(iii) *STI aspects scrutinized and/or problematized*: What facets of STIs are being explicitly scrutinized and/or problematized?

Another key variable concerns the aspects of STIs that are explicitly invited to be scrutinized and/or problematized. An STI normative framework that encourages scrutinizing and/or problematizing only the impacts of STIs may be perceived as less radical in its critical-reflective breadth than one that encourages *extending* this reflection or critique to the STI processes as well. In turn, the latter normative framework could be perceived as less radical in comparison to other frameworks that cumulatively allow for the problematization of the outcomes, processes, and purposes of STIs.

The separation between the domains of impacts, processes, and purposes is purely artificial. They are de facto intertwined. Thus, the discussions that can take place around the outcomes of STIs can sometimes be modulated by positions on issues related to their processes and purposes. However, if the main objective is to pursue more radical ways of scrutinizing and/or problematizing STI, it would be necessary to make these interrelations visible and to subject all these aspects to explicit scrutiny and/or problematization. Limiting the dimensions of STI that can be scrutinized and/or problematized to the outcomes would mean leaving open the possibility that some questions about the purposes and processes embedded in STI projects will be overlooked (even though positions on the latter may inform positions on outcomes).

Moreover, the scrutiny and/or problematization of STI outcomes, processes, and purposes does not come out of nowhere but involves socio-epistemically situated practices in space and time. An STI normative framework could go further by placing the assumptions and socio-material dynamics that underlie the process of scrutiny and/or problematization themselves at the center of explicit (meta-)reflection and/or (meta-)critique. For example, a framework that aims to promote responsible Artificial Intelligence (AI) by problematizing the outcomes, processes, or purposes of AI would represent a more

extensive critical-reflective radicality if it were committed to simultaneously situating this problematization itself within socio-material settings in which both the dynamics of AI and the ways in which AI is approached and framed are shaped and colonized by socio-material meanings (see Grunwald 2020). This contextualization is necessary to avoid problematizing the various aspects of an STI within the constraints set by the assumptions, problem definitions, and (futuristic) propaganda typically present in the narratives and discourses mobilized around the STI in question (e.g. in visions and socio-technical imaginaries).

Similar to the case of inclusivity, these comprehensive criteria need to be complemented by intensive criteria. Indeed, it would be important to pay attention to how deeply the outcomes, processes, purposes and/or underlying socio-material conditions and assumptions are actually (un)problematized.

(iv) *Operational positioning*: How are STI problematizations intended to shape STI dynamics?

The last of the tentative variables relates to how the scrutiny and problematization of STI are operationalized in relation to STI dynamics. A normative framework that proposes modes of STI problematization and/or scrutiny at specific junctures of assessment and that is conducted by external agencies or independent of STI practices (e.g. parliamentary TA) may be considered less radical than a normative STI framework or approach that proposes problematization of STI through processes of parallel accompaniment of STI research and development (e.g. the ELSA/ELSI project). Conversely, a normative framework or approach that proposes the problematization of STI through parallel processes that accompany STI might be considered less radical than another that promotes a critique of STI rooted in the research and development or socio-technical co-production processes themselves. External and punctual, parallel, and 'ingrained' forms of STI problematization represent and urge the promotion of different cultures of reflexivity and critique in, with, of, and for STI.

These extensive variables that characterize the degrees of radicality of the operationalization ('external,' 'parallel,' or 'ingrained') should be supplemented by intensive variables. For example, it would be worth considering whether the reflection or critique taking place within each of these operational positionings is constrained by pre-established normative principles from the top down, or whether the source of normativity for orienting and shaping STI trajectories emerges from the ongoing critical-reflective processes themselves (e.g. Ruggiu 2019).

To summarize this section's findings, STI normative frameworks and their associated (anticipatory) interventive practices exhibit varying degrees of critical-reflective affordances when it comes to fostering openness in STI co-production processes. The degree of critical-reflective affordances might depend on the positioning of each normative framework/intervening practice with respect to at least the following two aspects. First, it depends on whether STI normative frameworks and their associated interventions prioritize reflection (i.e. scrutiny and self-awareness) or take a more radical approach by encouraging critique (i.e. problematization and the search for alternatives). Second, it depends on the breadth and depth that this reflection or, more radically, this

critique, in turn, is invited to acquire (theoretical affordances of STI frameworks) or acquires (empirical affordances of associated interventive practices). The breadth of reflection and/or critique (i.e. the extensive critical-reflective radicality) afforded by STI normative frameworks and their associated practices could be identified and/or assessed depending on how their calls for reflection and/or critique position and encompass each of the variables proposed in Table 2. Different normative STI frameworks that afford varying degrees of critical-reflective radicalities coexist. Since the different degrees of radicality reflect different ambitions to open up STI, and since normative frameworks in practice have to deal with socio-technical systems prone to perpetuation and closure (Stirling 2008), the ease of fulfilling the critical-reflective ambitions of each normative framework is inversely proportional to its intended extensive and intensive radicalities.

It is important to note that the variables proposed here and summarized in Table 2 are also subject to the discourse on affordances that has been applied to STI normative frameworks. The variables suggested afford the scrutiny and problematization of certain constitutive features of the degrees of radicality of STI normative frameworks and related practices while inevitably overlooking others. For this reason, the proposed variables are explicitly considered tentative and open to possible further critique, expansion, and refinement. In the absence of an explicit theorization of the degrees of critical-reflective radicalities of STI normative frameworks, this conceptualization can serve only as a starting point. The following section discusses the entanglements that anticipatory exercises may have in relation to the proposed variables, especially in relation to the STI aspects being scrutinized and/or problematized through engagements with futures.

Gradients of reflective and critical insight through engagements with futures: the affordances of interventive anticipatory practices

The previous section argued that the theoretical critical-reflective affordances that anticipation can and seeks to enable are *ex-ante* modulated by the theoretical goals and critical-reflective affordances of the STI normative frameworks that anticipation seeks to serve. The question then should not only be whether an STI normative framework is 'anticipatory' per se, but rather what extensive and intensive critical-reflective radicalities these frameworks, and consequently their anticipatory dimension, afford.

Anticipation can indeed be at the service of STI normative frameworks that are, for example, on the most radical end of the spectrum with respect to the temporality variable (i.e. that incite to scrutinize and/or problematize STI *ex-post*, *ex-dure*, and *ex-ante*) but are not so radical in terms of the other variables. An example of this could be some early reformulations of parliamentary TA (see Brooks 1976; Grunwald 2002). These were tempted to use foresight techniques to enact an *ex-ante* and *ex-post* problematization of STIs [temporality variable]. Moreover, they were mainly informed by the perspectives of STEM experts and (some) users [inclusivity variable], focused mainly on the negative impacts of STI [problematized STI aspects variable], and conducted with the aim of providing externalist advice [operational positioning variable] (compare with Table 2).

Simultaneously, anticipation can serve STI normative frameworks that could theoretically be granted greater critical-reflective radicality. For example, the enactment of

engagements with futures to promote capacities and inform action in the present is also operative for RI. RI, as characterized by Stilgoe, Owen, and Macnaghten (2013), encourages an opening of STI to collective problematizations [inclusivity variable] of its outcomes, processes, purposes, and underlying guiding visions and expectations [STI aspects variable]. Moreover, this problematization should take place throughout the whole STI process [temporality variable]. Although the operational positioning variable is not explicit in RI, one can find clues indicating how RI could be operationalized within STI practices themselves.

While all variables are relevant for understanding the pragmatic critical-reflective affordances of anticipation and should be considered in combination, one of the aspects that deserves attention is the relationship between the modes of anticipation and the variable regarding the STI aspects under scrutiny and/or problematization. A foresight-based anticipatory exercise can facilitate the inclusion of different actors, regardless of the mode of engagement with futures in which it is articulated. Similarly, the heuristics of a foresight exercise can be used to promote external advice, to accompany STI in parallel, or to stimulate reflection 'from within' STI dynamics. Much more specific or closed, however, are the relationships between the modes of anticipation and the scrutinized and/or problematized STI domains. Each mode of engaging with futures facilitates certain dimensions of STI to be problematized (while hindering or complicating the problematization or scrutiny of others).

Specifically, and excluding the predictive modes of engagement with the future, anticipatory exercises can be articulated in the following modes of foresight-type engagements with representations of 'futures,' resulting in different types of foresight-based anticipations:

- *Strategic*: This type of anticipation is based on projections of alternative causal chains that may lead to the realization or avoidance of an (un)desired future. The main function of this type of anticipation exercise is to generate reflection and/or critique about the alternative ways to achieve or avoid previously established future goals. Although they are an ideal tool for promoting reflection and/or critique about the processes that STI might follow and for promoting resource management, the cognitive and epistemic processes they require often lead to taking the (un)desirable future for granted or even flirting with deterministic positions.
- *Exploratory*: This mode of anticipation is based on exercises involving the projection of different representations of the future. The main function of this type of anticipatory exercises is not to reduce uncertainty but rather to generate reflective capabilities aimed at embracing complexity and uncertainty, as well as to develop critique by pluralizing the range of (im)plausible and (un)desirable futures. This mode of anticipation can be divided into two subtypes:
  ○ *Evocative*: The anticipatory heuristics are based on diverse futures evoking or depicting socio-technical (e.g. Rip and Kulve 2008; van der Burg 2009) or techno-moral co-evolutions (e.g. Arnaldi 2018; Swierstra, Stemerding, and Boenink 2009). They constitute a tool to generate critique or reflection and to evaluate the potential impacts of the STI (positive and negative) on natural, social, technical, and/or axiological and moral systems.

○ *Normative*: The anticipatory heuristics are based on the imagination and scrutiny and/or problematization of the futures that are considered (un)desirable. This type of anticipation often precedes strategic anticipation (it helps to set the range of (un)desirable futures). It is a valuable tool for examining or problematizing the purposes of STI.

• *Critical-hermeneutic*: This kind of anticipation is based on engagements with representations of the future that promote their analysis and deconstruction. It calls for a dissection of the meanings and discursive and material agencies embedded in futures that de facto colonize STI practices in the present (e.g. visions, expectations, imaginaries, existing scenarios, anticipatory assumptions in scripts and prototyping). The focus is on examining, interpreting and/or critiquing the meanings that circulate in our ways of thinking about the future and in the social and material structures that underpin and support these ways of thinking. This mode of anticipation is typical of critical futures studies within A&FS (e.g. Inayatullah 1990) and within hermeneutic modes of TA (e.g. Grunwald 2020) and vision assessment (e.g. Grin and Grunwald 2000; Schneider, Wilke, and Lösch 2022).[10]

All forms of engagement with the future and corresponding forms of anticipation are heuristically valuable. Indeed, they are often operationalized in combined ways (see Urueña 2023). However, the engagement with the future that each mode of anticipation engenders facilitates the problematization or scrutiny of certain aspects of STI. The modes of anticipation could thus be correlated with the extensive degrees of critical-reflective radicality discussed in the previous section, as depicted in Table 3.

Practical insights for the enactment of anticipation

The findings presented in the previous pages, while theoretical, preliminary, and open to future refinements, have several practical implications for both the STI normative frameworks and the anticipatory practices associated with them. For example, in assessing the critical-reflective radicality of anticipation, these findings call for a greater focus on the

Table 3. Correlations between the STI aspects scrutinized and/or problematized and the modes of anticipation.

Extensive Radicality	Variable	Associated mode of anticipation
	STI aspects scrutinized / problematized	
Less radical	STI outcomes/impacts: • Negative impacts • Right impacts	Exploratory – evocative
	STI processes STI purposes • Technical-functional purposes • Socio-political purposes and orders	Strategic Exploratory – normative
More radical	Underlying assumptions, values, and socio-material conditions reifying futures (e.g. problem definitions, visions, expectations, imaginaries, structures)	Critical-hermeneutic

spaces of reflection and/or critique afforded by the concrete STI normative (reconfigured) framework demanding anticipation. The main suggestion is to always situate anticipation *in relation to* the critical-reflective ambitions of the STI framework it is meant to serve.

This process of assessing anticipation in relation to the (reconfigured) normative framework at hand involves several steps. First, it is necessary to consider whether the normative framework in question is committed to fostering reflection or, more radically, to enacting critique. All forms of critique require some degree of reflection, but only the former affords the imagining of alternatives and thus serves as a resource for enacting change. Once it has been determined whether the normative framework is committed to promoting reflection or critique, it is appropriate to examine the extensive and intensive radicalities that this critique or reflection acquires.

The variables outlined in section 3 (Table 2) can facilitate the identification of the extensive critical-reflective radicalities of STI normative frameworks and/or their associated anticipatory practices. In practice, these criteria can be used for a variety of purposes. While this article is limited to the grounding of these variables, some of their potential practical applications can be hinted at. For example, the variables could be applied to individual STI normative frameworks to clarify their critical-reflective stances (or even to reveal a possible lack of specificity with respect to some of these variables). This could apply both to the STI normative frameworks as they are theoretically defined in scholarly texts and to their potential respective reconfigurations that ongoingly emerge through their concrete implementations and/or 'transductions' within/for/to specific settings (Doezema et al. 2019). The variables could also be used to conduct comparative analyses (i) between the critical-reflective radicalities of different frameworks (e.g. comparisons between differentiated frameworks, or between a framework as defined in its foundational texts and as defined/practiced through its associated potential 'transductions'), and (ii) between frameworks and their corresponding (anticipatory) interventive practices. The latter may be useful not only in checking for a possible gap between expectations/ambitions and the actual spaces of critique or reflection opened up but also in improving intervention practices themselves by encouraging (self-)reflection/criticism on the critical-reflective affordances characterizing anticipatory methodological designs and operationalizations.

The links presented between the aspects of STI to be problematized and the forms of engagement with futures that different forms of anticipation represent (section 4, Table 3) are also of practical relevance. Each aspect of STI to be problematized (e.g. outcomes, processes, goals, underlying assumptions, visions, and socio-material dynamics) requires specific ways of engaging with futures and thus the activation of different modes of anticipation. An STI normative framework that aims to promote radical forms of reflection and critique by covering the problematization of different facets of STI will stimulate (in its discourse) and will be prone to accumulate (in practice) intervening anticipatory practices based on different kinds of engagement with futures.

Since critical-hermeneutic engagements with 'futures' are meta-representational, they theoretically afford a second-order, more explicit kind of reflection and/or critique. Critical-hermeneutic engagements with futures are not bound to problematize and/or scrutinize the future outcomes, processes, and purposes of STI *per se* but primarily to open up

the circulating assumptions, framings, problem definitions, and socio-material orders and dynamics that underlie and inform these forms of scrutiny and problematizations. If an STI normative framework aspires to exhibit radical critical-reflective affordances, it must promote the problematization of the underlying elements that commonly shape the production of STI problematizations themselves. This means adopting, initiating, and sustaining a critical-hermeneutic approach throughout the processes of implementing the other modes of anticipation.

The critical-hermeneutic approach to futures can be observed in the context of STI normative frameworks in vision assessment (e.g. Grin and Grunwald 2000; Grunwald 2004; Schneider, Wilke, and Lösch 2022) and, more recently, in the hermeneutic approach of TA (see Grunwald 2014, 2016, 2020). Both vision assessment and hermeneutic TA ultimately call for situating future mobilizations and the use of future temporality itself in the present context, thereby creating a certain distance with representations of the future and emphasizing the inherently contingent nature of anticipatory phenomena. This involves interpreting the appeals to future temporality and their associated framings (e.g. associations of STIs with continuous growth, progress, technological solutionism, somnambulism and triumphalism, or the domination of nature) and the mobilized 'futures' as expressions of the present. As such, critical-hermeneutic analysis and critique can provide useful heuristics regarding the existing anxieties, modes of living temporality, hopes, dissatisfactions at the time of the creation and mobilization of futures. The specific modalities through which this distancing occurs have evolved over time to include more passive or proactive forms of 'assessment' and 'transformation' (see Wei-Kang Liu 2023).

This distancing and critical-hermeneutic approach is motivated by different goals or the pursuit of different heuristics (some of which are interrelated and mutually reinforcing). The need to apply a critical-hermeneutic approach, even when not explicitly qualified as such, has been driven primarily by the need to examine (reflection), evaluate, and question (critique) the underlying cognitive, aesthetic, emotional, and/or normative (anticipatory) elements and framings embedded in or supported by 'futures' and the future-oriented mode of thinking. This is intended both to counter the highly speculative nature of many visions and the reification of futures (e.g. Nordmann 2007; Nordmann and Rip 2009) and to increase awareness and critique of the spaces of possibility afforded by temporal regimes and by discursive and material artifacts (e.g. Dickel 2023) that embody 'futures.'

At a more fundamental level, the critical-hermeneutic approach has also been proposed as a means of scrutinizing (reflection) and challenging (critique) the agencies at work in the mobilization of futures. This involves making visible and critiquing the socio-material mechanisms and power dynamics that underlie and foster the mobilization of particular futures and meanings (to the detriment of alternative ones), as well as specific ways of using the future and temporality. For example, the hermeneutic approach of TA encourages tracing and critiquing the conditions of production and co-evolution of 'hermeneutic circles' and how their embedded meanings colonize perceptions of STIs and position them as the very object of problematization (Grunwald 2020). The recent approach to vision assessment, known as 'transformative vision assessment,' specifically calls for the integration of semiotic approaches into vision assessment processes so that they are more sensitive to how STI problematization processes engage

with and reproduce hegemonic patterns of framing and giving content and form to futures (Dobroć and Lösch 2023).

Some of the heuristics mentioned above, derived from critical-hermeneutic engagements with futures, can also be understood as anticipatory modes of enacting what in A&FS is called 'futures literacies' (see Miller, Poli, and Rossel 2018; Miller and Sandford 2019; Poli 2021). 'Futures literacies' encompass a set of critical-reflective capabilities and ways of thinking about how futures are co-produced, imagined, and used, and how they are shaped by and serve particular power dynamics (e.g. how and why they promote particular actions in the present) (Mangnus et al. 2021). These capabilities are often fostered, developed, and strengthened through foresight exercises that promote critical-hermeneutic engagements with futures. Futures literacy practices often aim to generate 'emancipation' by helping to recognize the potential agency of social actors and to bring forth voices and 'profane futures' (Groves 2023) that have historically been illegitimately silenced.

While vision assessment, hermeneutic TA, and futures literacies embody forms of reflection and critique, attention should be paid to the breadth and depth of their critical-reflective radicality. For example, when creating futures literacies in STI contexts, we should consider whose capacities are being empowered, when these empowerments occur, what aspects of STI are being promoted for critique and/or reflection, and how these capacities, problematizations and/or scrutiny challenge or reproduce current STI dynamics (see Table 2). Any form of anticipation, including critical-reflective scrutiny of STI, needs to be aware of the (de)politicizing mechanisms that shape actors' accounts of what is seen as (un)desirable or (im)plausible. Critical-hermeneutic engagements offer valuable ways to engage with futures, but they are not neutral and can both open and close spaces of possibilities. Evaluating the critical-reflective scope of any anticipatory intervention requires considering whether, how, and to what extent it challenges or reproduces the multiple futures that constitute the broader politics of anticipation in which it is enmeshed.

Conclusions

Calls for reflection and/or critique through anticipation have not been accompanied by specific theories and criteria to determine the radicality that this reflection and/or critique can (theoretically), should (normatively), or does (practically) assume. What is the nature of the reflexive or critical capacities we are trying to activate? On what aspects should this reflection and/or critique be practiced? How extensive and intensive are these reflections and/or criticisms?

The present paper aimed to advance the theoretical development of anticipation as a dimension for promoting more robust STIs by exploring the critical-reflective affordances that anticipation offers for problematizing STIs. Ultimately, the goal was to tentatively provide conceptual and interpretive tools to address the questions raised above.

The paper's insights support four main conclusions:

– The scrutinizing and/or problematizing affordances that anticipation can and seeks to enable are modulated by the theoretical goals and problematizing affordances of the STI normative frameworks that anticipation seeks to serve.

- Reflection and critique have distinct heuristics: Normative frameworks and their associated anticipatory practices aimed solely at fostering extrospective reflection or reflexivity may offer more conservative (or less radical) insights for illuminating alternative pathways of transformation than those that focus on or build upon critique.
- The critical-reflective affordances of STI normative frameworks can be assessed in terms of their breadth (gradients of extensional radicality) and/or depth (gradients of intensional radicality). The extensional critical-reflective radicality of STI normative frameworks and their associated anticipatory practices can be identified by attending to the interplay of at least four variables: (i) temporality, (ii) inclusivity, (iii) STI aspects scrutinized/problematized, and (iv) operational positioning in relation to STI practices.
- Strategic, exploratory (evocative or normative), or critical-hermeneutic modes of anticipation each facilitate the scrutiny and/or problematization of specific aspects of STI. The critical-hermeneutic mode of anticipation affords deeper forms of scrutiny and problematization of STI. This is because it invites meta-reflective and/or critical engagements with the assumptions and dynamics that underlie both STI practices and the very processes of problematizing their outcomes, processes, and purposes. This mode of anticipation promotes a questioning of the (im)plausibility and (un)desirability of the assumptions, framings, and dynamics that shape how we imagine the future of STI. For these reasons, the article suggested the need to initiate and articulate diverse anticipatory processes on a critical-hermeneutic approach and/or to foster critical-hermeneutic capacities.

The insights offered in this paper remain tentative. They can serve as a preliminary starting point for assessing the gradients of critical-reflective breadth and depth afforded by STI normative frameworks and their associated anticipatory practices. However, further research is needed to critique, refine, and extend the variables proposed here for this purpose.

Notes

1. It is important to note that AG, RRI, RI, and TA have varying degrees of explicit integration of anticipation as a key procedural dimension. While AG, RI, and newer TA approaches explicitly recognize anticipation as a key procedural dimension, RRI's explicit mention of anticipation is not consistent. However, some prominent proponents of RRI, such as René von Schomberg, acknowledge that RRI 'creates the possibility for anticipatory governance' and associate RRI with anticipating 'positive and negative impacts or, whenever possible, defin[ing] desirable impacts of research and innovation' (von Schomberg 2013, 65) through technology assessment and foresight (see also von Schomberg 2012, 51–52). In addition, there are instances where RRI is encouraged to incorporate the procedural dimensions of RI: 'anticipation,' 'responsiveness,' 'reflexivity,' and 'inclusion' (e.g., Commission 2013, 57–58; van de Poel et al. 2017, 5–6). However, Owen and Pansera (2019) argue for differentiating between RRI and RI.
2. According to Grunwald (2002, 124), the term 'classical TA' is problematic as it fails to acknowledge the actual heterogeneity of early forms of understanding and practicing TA. It misleadingly suggests that all TA practices were uniformly characterized by (i) a division of labor between science and politics, (ii) a statist orientation, (iii) an emphasis on quantification, (iv) reliance on experts, and (v) a strong emphasis on technological forecasting.

3. The contemporary literature in A&FS legitimately distinguishes between 'anticipation' and the practices of 'foresight' and 'forecasting' (Poli 2019a, 2019b). However, this distinction has not always been clear (Poli 2021, 2–3). While forecast and foresight involve specific techniques for constructing and engaging with future models, anticipation goes a step further by translating their heuristics into action. 'Put briefly, forecasting deals with data extrapolation, foresight with the visualization of possible futures, and anticipation with their translation into action' (Poli 2021, 3). However, since the main objective of forecasting and foresight exercises in STI governance is to guide actions and/or enhance our capabilities, these terms are often used interchangeably in this context.

4. Foresight is now regarded as the main terrain of Futures Studies, but its epistemic foundations and pragmatic orientations are heterogeneous. Positions range from the claim that foresight should tell us something (albeit tentatively) about the not-yet, to the argument that it should remain technically 'futureless' in spirit (see Samet 2010; Sardar 2010). The latter perspective assumes that the future does not exist (ontological claim) and therefore we cannot look into it (we can only imagine it) (epistemic claim). Everything we do, then, is to engage with models that represent imaginations of the future that we, as socio-epistemic actors, contextually and contingently co-create and evaluate with our available resources.

5. When using the term 'anticipation,' each normative framework refers exclusively to a subset of all possible kinds of anticipatory practices. Each STI normative framework delineates its set of anticipations considered valid or useful based on its respective goals and normative visions.

6. Just as we can differentiate between extrospective and introspective modes of reflection, we can similarly distinguish between extrospective critique (where the object of critique is external to the system performing the critique) and introspective critique (where the system performing the critique is both the subject and the object of the critique). Introspective forms of critique are typically referred to as 'self-critique.' The relationships between extrospective or introspective reflections and extrospective or introspective forms of critique can take many forms. For example, the heuristics resulting from the introspective reflection of ethnographers on their own underlying values, conditions, and assumptions can later serve as a substrate for the enactment of both self-critique (e.g., the same ethnographers criticize their own previously self-scrutinized features) and/or critique (e.g., ethnographers can share the results of their reflexive endeavors and, once accessible to and accepted by other actors, these other actors can subject these findings to critique). Similarly, the heuristics resulting from the extrospective reflection of ethnographers on the epistemic cultures and values of nanoscientists can later serve as a substrate for the enactment of both critique (e.g., the same ethnographers may criticize these epistemic cultures and values and/or prescribe the desirability of articulating nanoscience in alternative ones) and/or self-critique (e.g., the ethnographers may share the results of their reflexive efforts with the nanoscientists scrutinized and, once accessible to and accepted by them, they may subject their own features to critique).

7. Since works of art can trivially be considered objects external to the subject conducting the examination or critique, the example of the fine art analysis guide is a hypothetical case of an artifact that prompts *extrospective* reflection and/or critique. A comparable instance in the context of *introspective* reflection and/or critique would be a guide for ethnographers to conduct a more reflexive and self-critical ethnography. Davies's (1999) guide, for example, invites ethnographers to open up to scrutiny a number of dimensions of their professional practice, such as the choice of topics and methods, modes of observation, participation, interviewing, structuring the research, formalizing the analysis, etc. All these points would denote the extensional radicality or breadth of the spaces of reflexivity or self-criticism that the guide affords. The intensional guide's radicality is manifested in the depth in which each of these elements is encouraged to be scrutinized and/or problematized.

8. Please note that to suggest that STI normative frameworks have a generic primary identity established by basic characterizations typically found in written texts does not imply that only those STI governance practices and capacities that have been shaped by the interventive practices associated with these normative frameworks can align with such generic identities. For example, Conley (2020) illustrates how governance practices that were not and could not be influenced by AG can be seen as latent forms of 'proto-AG.' However, recognizing these practices as latent forms of 'proto-AG' requires assuming a specific set of components of AG that are outlined in some of their respective foundational texts: 'The anticipatory governance concept is comprised of three different components – foresight, engagement, and integration, and are outlined in Barben et al. (2008)' (Conley 2020, 508).
9. Recognizing that (anticipatory) intervening practices are conditioned by the affordances of the frameworks with which they are associated should not lead to the misunderstanding that the theoretical and/or empirical affordances of intervening practices simply mirror the theoretical affordances of the frameworks they serve. Each normative framework defines a theoretical space of critical-reflective affordances. The expected critical-reflective affordances of its associated intervening practices will be situated with varying degrees of coupling to this previously theoretically defined space. The critical-reflective affordances empirically or de facto enabled by each intervening practice may, in turn, deviate more or less from the expected affordances of the interventions. Ultimately, the degree of openness or closure empirically afforded by anticipatory intervening practices will depend on many aspects (e.g., the design of the exercise, how it addresses the dynamics of closure that prevail in the socio-theoretical system in which it operates) (Urueña, Rodríguez, and Ibarra 2021).
10. One might ask whether critical-hermeneutic engagements with futures can constitute a mode of anticipation. In response, it should be noted that it is possible to inform action and activate capacities through these analytical-deconstructive engagements with futures models, thus complying with the basic definition of anticipation initially provided (see Example 4 at the beginning of section 2). Indeed, A&FS often consider foresight promoting analytical-deconstructive engagements as anticipatory means of developing criticism and futures literacies (Inayatullah 1990, 1998; Miller and Sandford 2019). The critical-hermeneutic mode of engaging with future models can be identified in those STI normative frameworks that position anticipation as a tool to generate critique or reflection about circulating visions and promises around STI (e.g., alluding to the need to conduct vision assessments and/or hermeneutic TA) (see Table 1).

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