Anticipation and modal power: Opening-up and closing-down the *momentum* of sociotechnical systems

Sergio Urueña
University of the Basque Country UPV/EHU
sergio.uruena@ehu.eus

Abstract
The last three decades have been particularly fruitful in identifying and theorising how representations that integrate assumptions about potential and (un)desirable futures function in the co-production and coevolution of sociotechnical realities. Within STS literature, there are three internally heterogeneous approaches to the creation and mobilisation of futures: descriptive, critical-normative, and methodological-interventive. Visions, expectations, and imaginaries are currently recognised as *de facto* anticipatory artefacts that close down the *momentum* of sociotechnical systems and, as such, they are also normatively considered as objects of critical scrutiny. At the same time, interventive techniques engaging with future representations (such as foresight) are considered by recent normative frameworks as useful anticipatory instruments for opening-up the range of envisaged alternatives. This article reviews STS advancements on the performativity of both *de facto* and interventive anticipatory practices in shaping the *momentum* of sociotechnical systems in light of the phenomenon of modal power (i.e. the modulation dynamics of what actors deem to be "(im)plausible" and/or "(un)desirable"). In the process, the article theoretically argues that the diverse attempts of STS scholars and practitioners to understand, critique, and interventively engage with the politics of opening-up and closing-down the *momentum* of sociotechnical systems through future representations requires engaging with the creation, mobilisation, and execution of modal power. The heuristics presented in this review article are intended to be useful in framing and recognising the political-epistemic radicality that the creation and mobilisation of sociotechnical futures holds in the constitution of our sociotechnical orders, as well as the role that the attribution of (im)plausibility or (un)desirability plays in such processes.

Keywords Anticipation • Modal Power • Sociotechnical Futures • Plausibility • Technological Momentum • Sociotechnical Imaginaries • Foresight • Future-making Politics

Over the last three decades, science and technology studies (STS) has shown a growing interest in how sociotechnical futures shape the ongoing co-production and coevolution of science and technology with society. Material and discursive sociotechnical entities that contain implicit or explicit assumptions about the future—such as expectations, visions, and sociotechnical imaginaries—have become an important analytical focus of scholarly work. These entities constitute an important part of the ongoing dynamics that orient scientific-technological activities (Borup et al., 2006; Jasanoff and Kim, 2015; Konrad and Böhle, 2019; Lösch et al., 2019).

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Anticipatory dynamics—those guided (consciously or unconsciously, intentionally or unintentionally) by future representations (Poli, 2017; Miller, 2018; Poli and Valerio, 2019)—are currently addressed within STS from three ideal-typical approaches:

(i) *Descriptive approaches* aim to elucidate the diverse performative roles and impacts of future representations (whether in the form of scripts, visions, sociotechnical imaginaries, or expectations). The focus here is typically on describing how futures shape heterogeneous sociotechnical assemblages.

(ii) *Critical-normative approaches* emphasise the duty to open up futures by subjecting them to critical analysis and reflexive governance. STS research conducted under a critical-normative approach criticises hegemonic futures and suggests the promotion of alternative, more desirable ones.

(iii) *Methodological-interventive approaches* use techniques that engage futures representations (e.g. foresight, visioning or futuring practices) in order to proactively open up the *de facto* anticipatory dynamics. Here anticipation is typically used as a heuristic resource to proactively support normative STS commitments.

Anticipation thus simultaneously appears within STS as an *object of research*, an *object of critical analysis*, and a *means for intervention* (Konrad et al., 2016; Bechtold et al., 2017). STS scholars are observers, producers, modellers, and users of future representations. They are thereby involved in multiple forms in the anticipatory dynamics of opening-up/closing-down the potentialities of sociotechnical pathways (Stirling, 2008).

This review argues that these anticipatory dynamics are constituted, motivated, and conditioned by what Steve Fuller (2018: 139–149) calls "modal power"—the modulation of what actors cognitively and affectively deem to be "(im)plausible" and/or "(un)desirable". Diverse STS engagements with the anticipatory politics of opening-up/closing-down the *momentum* of sociotechnical systems can be understood as attempts to trace, assess, and co-shape how the (im)plausible and the (un)desirable are fixed by futures which encode the directionality of our present actions.

The argument builds on three key concepts: "sociotechnical *momentum*" (Hughes, 1969; 1994), the opening-up and closing-down of sociotechnical possibilities (e.g. Stirling, 2008), and "modal power" (Fuller, 2018: 139–149). It aims to facilitate the understanding of the limits, challenges, and potential political-epistemic radicality of STS work that engages with sociotechnical futures. STS scholars are often driven by the commendable motivation of opening-up or democratising futures. However, through their participation in modal power allocation processes, STS scholars could also subtly contribute to stabilisation and closure dynamics which reify sociotechnical futures and solidify ongoing sociotechnical commitments.

The argument unfolds as follows. The first section outlines the role anticipations play in shaping the *momentum* (i.e. the direction and speed) of sociotechnical systems' paths, as well as how STS scholars have engaged with this phenomenon. The second section addresses the politics of opening-up/closing-down science and technology governance processes through anticipatory dynamics. Concretely, I conceptualise how anticipation is an instrument for, and simultaneously a product of, the mobilisation and exercise of modal power. This implies recognising that the function of anticipatory exercises is the mobilisation and modulation of what actors consider "(im)plausible" and "(un)desirable". It is by virtue of this modulation that the performativity of anticipatory artefacts such as predictivist regimes, scripts, expectations, visions, and imaginaries becomes socio-politically significant. The third section draws on the above findings to

argue that when STS scholars attempt to open up, expand, and/or enrich the futures under consideration through foresight or futuring practices, these interventions are primarily aimed at redistributing modal power. More specifically, I emphasise that these STS interventive practices engaging with futures can only democratise current anticipatory choices by proposing genuinely alternative futures if they disrupt the socio-material mechanisms that underlie and sustain current patterns of modal power allocations. The article ends with a series of concluding remarks.

"The future" in the co-production of sociotechnical worlds: Constituting *momentums* through anticipatory artefacts

Sociotechnical configurations shape our physical, affective, moral, and legal environments. They channel the relationships we establish with others (both humans and non-humans) and thereby "enable and constrain basic human possibilities" (Jasanoff, 2016: 9). Sociotechnical assemblages co-constitute the scene and integrate the organisation and rules through which our existence (and its meanings) takes root and flourishes. Sociotechnical systems are playgrounds of (and for) power.

This section aims to emphasise that the anticipatory dynamics are a key element when addressing how these enabling/constraining spaces of possibility are established. The dynamics of anticipation are those activated by means of future-oriented artefacts such as predictive regimes, scripts, imaginaries, visions, and expectations. They co-shape sociotechnical systems, playing an important role in opening-up/closing-down sociotechnical systems' *momentum* (i.e. their speed and directionality of development). STS scholars have addressed these anticipatory dynamics—even if not always named and identified as such—under a variety of approaches.

The momentum *of sociotechnical systems: Mass, direction, and speed of development*

The concept of technological *momentum* has been used as a heuristic resource to explain the historical coevolution of different social and technical phenomena (e.g. Nye, 2006; Wang and Burton Swanson, 2008; Boslaugh, 2011; Povlock, 2016). Thomas P. Hughes introduced this metaphor in 1969 with the aim of analysing and explaining the dynamic forces that fuel the development of large technological systems (e.g. the airline industry, electrical systems) (Hughes, 1969; 1983). Hughes recognised that in such systems both technical and social components reciprocally interact and mutually constitute each other, and hence his technological systems can be understood as sociotechnical systems (Hughes, 1994: 101, 105).

The metaphor draws inspiration from Newtonian mechanics, where the concept of *momentum* describes a mass *in motion*. Any object that is moving has a vectorial force that constitutes its *momentum*. As such, *momentum* describes both magnitude (how much force defines the mass movement) and direction (the mass's heading path). When momentum is applied as a heuristic concept to complex and non-deterministic systems, such as sociotechnical ones, it serves to emphasise that sociotechnical systems are not static entities, but rather that they are co-constituted *in motion*, through their ongoing processes of coevolution.

In this sense, the concept of sociotechnical *momentum* (hereafter "STM") involves considering the interactions between three abstract elements that co-constitute sociotechnical systems through time (Hughes, 1987: 76):

- *Mass*: the series of assembled components—human and non-human actors—that constitute the sociotechnical system;

- *Direction*: the more or less defined orientation towards which the dynamic system seems to coevolve;
- *Velocity*: its rate of expansion or growth.

The concept of STM was proposed by Hughes to explain the Collingridge dilemma (Collingridge, 1980): why do successful sociotechnical systems tend over time "to resist changes in the direction of [their] development"? (Hughes, 1983: 140). Sociotechnical systems tend to be more flexible and open (i.e. more susceptible to modulation of their features and directions) in their early stages of co-production and coevolution, and they become successively more fixed (i.e. less susceptible to modulation) as they grow and consolidate. Growth and consolidation are understood in terms of the expansion of actors, interconnections, and complexity defining the sociotechnical system in question. For Hughes, it is the high degree of *momentum* that certain sociotechnical systems gradually acquire over time (by growing, competing with alternatives, and consolidating) that provides their stability and firmness. STM thus hinders the possibilities of re-shaping the attributes and orientation of sociotechnical systems' development.

Hughes proposed the *momentum* metaphor as a "more complex, flexible, time-dependent, and persuasive" (Hughes, 1994: 102) explanatory theory of technological change than those offered by social and technological determinism (in which the explanans for sociotechnical phenomena is reduced to the agency of social or technical actors, respectively). For Hughes (1994: 102), both social and technological determinism "suffer from a failure to encompass the complexity of technological change"; a complexity in which the social and technological agencies inherently hybridise and mutually co-constitute each other. Sociotechnical change shapes and is simultaneously shaped by a constellation of socio-cultural, economic, and technical factors.

The degree of influence of each of the abstract poles is, however, asymmetrical over time: in Hughes's words, "as they grow larger and more complex, systems tend to be more shaping of society and less shaped by it" (Hughes, 1994: 112). The degree of influence of the "social component", so to speak, is conceived as inversely proportional to the degree of *momentum*. In the initial phases of development, social agency predominates, while in advanced phases the technological agency becomes more prominent. Sociotechnical systems tend to gain *momentum* as they grow in size and maturity, *diminishing* (without totally abolishing) the capacity of societal actors to change their characteristics and orientation (Hughes, 1987: 54). Highly mature, deep-rooted, and large sociotechnical systems are more difficult to shape because they tend to force new and existing innovations to adapt to their requirements (which is to say, they tend to hinder the generation of alternatives that contradict or threaten their own persistence). The phenomena of STM is thus related to STS concepts such as "closure" (Bijker et al., 1987; Misa, 1992), "stabilisation" or "flexibility" (Misa, 1994; Hanseth et al., 1996), as well as "irreversibility" (Callon, 1990).

A brief historical case may illustrate the idea of STM. As David E. Nye (2006: 54–56) notes, various societal actors had to choose between using two ranges of supply voltage—100-127v versus 200-240v—and transmission systems—direct current (DC) versus alternating current (AC)—during a protracted historical process. These decisions were influenced by a variety of variables, such as the power and status of the actors pushing each alternative (e.g. Edison's companies), financial commitments, the existence of patents, the infrastructure available at the time (e.g. wiring infrastructure, facilities for installing power plants), the level of energy demand, or the availability of

other artefacts (e.g. transformers). The complex arrangement of contingent and spatiotemporally situated choices gradually configured the characteristics of different sociotechnical systems in different geographical areas. In North and Central America, the 100-127v voltage range and DC transmission systems (i.e. Edison's mode) were established very early, while in the rest of the world (especially in Europe) the 200-240v single-phase voltage range and the use of AC transmission systems (i.e. Tesla's mode) were the norm from the outset. Although AC was eventually adopted as the standard form of power transmission, the voltage range in North America, Central America, and some South American countries remains at 100-127v—notwithstanding that in some areas of these countries, homes, buildings, and utilities also accommodate two-line systems at 120+120v. *Once the electricity grids were set to 100-127v and the production of technology (e.g. lamps and some household appliances) and wiring systems were adapted to this voltage in certain geographical areas, the possibility of modifying the prevailing sociotechnical voltage regime was considered extremely costly, both logistically and economically* (apart from the safety arguments in favour of remaining in the lower voltage range). The 100-127v standard materially set the basic sociotechnical conditions of possibility from which all further developments were framed. In North, Central, and some parts of South America, the use of 100-127v was initially a matter of choice, but once it gained *momentum* and became standardised, it influenced the range of alternative directions of development that were seen as plausible and feasible by later generations. It is in this sense that Hughes argues that sociotechnical systems with high *momentum* "exert a soft determinism" (Hughes, 1987: 54–55).

This soft determinism, however, does not imply a fatalistic *autonomy* of sociotechnical systems. *Pace* Vermaas et al. (2011: 89), Hughes' STM theory does not assume that "systems go their own way, and in those situations, society seems to have no alternative but to adapt to that path". STM is dependent on how the interlocking mechanisms and intertwined constituent actors of the sociotechnical systems in question coevolve (e.g. institutions, physical and bureaucratic infrastructures, technologies, cultural and economic orders, norms and laws, institutions, etc.). In this sense, STM "is not irresistible" and "can be made to change direction if a variety of its components are subjected to the forces of change" (Hughes, 1994: 112–113). The possibility for changing these ensembles exists, but STM makes it an arduous and costly undertaking. The "soft determinism" that STM exerts thus rather resides in its function of constraining the *possibilities* considered potentially realisable. For instance, the high STM of the internet hinders the possibility of shaping *nowadays* the co-construction of *future* sociotechnical worlds not permeated by this technology. Many of the technological devices being developed today converge with (and at the same time perpetuate) its existence. It is not that the internet acquires its own autonomy, but that its ongoing sociotechnical coevolution and *momentum* have progressively shaped the feasibility of future world paths. In a nutshell, STM stresses that proposing and pursuing highly disruptive directions finds its most immediate constraint or limit in the socio-material and organisational characteristics of sociotechnical systems and their tendency to self-preservation and self-perpetuation.

The STM metaphor provides a diachronic and dialectical approach in which processes of sociotechnical co-production and coevolution are subject to (and at the same time producers of) hybrid socio-cultural and technical forces and political motivations throughout the whole set of processes. This approach allows us to move away from the illusory and dangerous image that reduces the roots of technological development and change to technological autonomy. It leaves enough room for politics

and decision-making (navigating somewhere between the illusion of total control and the complete absence of control) while recognising technologies as simultaneously co-creations and instruments for world-making; as vehicles and objects of the ongoing and dynamic constitution of politics (Winner, 1980). Sociotechnical orders established in the course of historical processes matter, but there is always room for active human agency, and thus the total rigidity of technological lock-ins and predetermined or fixed paths assumed in some discourses is relativised (Jasanoff, 2015: 1–3).

Anticipation and the formation of sociotechnical momentum

Anticipatory practices are a crucial component of the constellation of practices that shape STM. Anticipation, understood as an activity or action that is informed (consciously or unconsciously) by representations or images of potential futures (Poli, 2017; Miller, 2018; Poli and Valerio, 2019), is simultaneously *constitutive of* and *constituted by* the dynamics of sociotechnical systems (in terms of both growth rate and directionality).

Understanding how anticipation connects to STM requires an understanding of how inhabiting the not-yet—in terms of both modality (i.e. the heterogeneous modes and genres of approaching and living the future) and content (i.e. the depicted images of the future)—enacts individual and social life *in the present* (e.g. Bryant and Knight, 2019). It demands paying attention to how the prospective grammars underlying current future-oriented practices and "living futures" (e.g. forecasting methods, hopes, promises, visions, planning, imaginaries) perpetuate, stabilise, and transform our sociotechnical systems (Mische, 2009; 2014: 451–457). Anticipation consequently prompts us to attend to how futures are created, silenced/reinforced, and sustained/altered to steer sociotechnical coevolution processes towards certain projects and away from others (Adam and Groves, 2007: 198; Alvial-Palavicino, 2015; Jasanoff, 2015). The trajectory of nanotechnology is exemplary in this regard: futures were central to stimulating the *momentum* of nano development by supporting its legitimacy and socially anchoring it as a key "enabling" technology (Berube, 2004; Lösch, 2006; Selin, 2006; Anderson, 2007; Selin, 2007; Hanson, 2011; Parandian et al., 2012).

To understand the performativity of anticipation thus requires that we address not only how sociotechnical systems develop and unfold over *time*, but also how such historical development is embedded in, and modulated by, heterogeneous regimes or orders of *temporality* (see Selin, 2006). As Emirbayer and Mische (1998: 963) argue, the agentic dimension of social action can only be captured in its full complexity if it is analytically situated within the flow of temporality. Sociotechnical coevolution processes occur within contingent and evolving "*régimes d'historicité*" (Hartog, 2003; Koselleck, 2004). These *régimes d'historicité* express ways of being (i.e. experiencing and ordering) in time. Although the past, present, and future are inextricably interwoven in our individual and social experimentation with reality (Buckner et al., 2008; Doll et al., 2015; Seligman et al., 2016), these are not symmetrically articulated in guiding the directionality of our actions. The three dimensions always resonate. They co-jointly conform to what Emirbayer and Mische (1998: 970–974) call "the chordal triad of agency". However, they take on different intensities and tonalities depending on the situation and context.

STS scholars and practitioners have long been interested in *intentional* and highly *formal* uses of the future. For instance, classic works in the field have asked how forecasting and expert-based future modelling methods are simultaneously a product and a constructive element of efforts to "depoliticise" the future (e.g. Nowotny et al.,

2001; Jasanoff, 2003). Predictive approaches to the future and modes of orienting action on the basis of forecast models have proved to be instrumentally valuable to technocratic approaches, in which political-technical issues are reduced to their technical aspects. These techniques often serve to justify controversial decisions in political decision-making arenas as well as to establish the relevance of specific present events (see Sarewitz et al., 2000; Mallard and Lakoff, 2011).

STS has also been a central locus for the study of *informal* uses of the future that are not always intentional, conscious, and controlled.[1] Although this literature does not always use the term "anticipation" it is also concerned with the future-oriented character of science and technology and the role that futures play in enabling and constraining alternative possibilities. For instance, the Social Construction of Technology (SCOT) programme identified that "physical artefacts project into the future the socially constructed characteristics acquired in the past when they were designed" (Bijker et al., 1987: 77; Bijker and Law, 1992). Actor-Network Theory likewise considers how these future projections are embedded in so-called "scripts". Scripts are ascribed to technological artefacts during their design processes to mediate the experiences and behaviours of their (future) users. As Latour (1992: 244) illustrates, embedded in speed bumps is the script: "slow down your vehicle (or else break the suspension)!". Although scripts are not considered to fully determine experiences and actions, their role is to limit the future *possibilities of use* and *experience* by *prescribing* the performance of some actions instead of others (see Akrich, 1992; Latour, 1992). In this sense, the scripts operate as anticipatory elements that aim to constrain the sphere of *potential* meanings attributed to a technological artefact and the *potential* actions that could be realised through such an artefact.[2]

The late 1990s and early 2000s were particularly fruitful in terms of identifying and recognising that "[c]o-production processes include anticipation" and that "[t]echnical change is driven partly by the historical experience of actors, their views of the future, and their perception of the promise or threat of impacts which will change over time" (Schot and Rip, 1997: 257). The growing interest in the sociology of expectations at that time undoubtedly played an important role in this identification and recognition (see Borup et al., 2006). The sociology of expectations literature emphasised that promises and expectations form another important anticipatory element that dynamically shape science, technology, and innovation practices. Evidence from a number of empirical case studies illustrates how promise-based rhetoric and expectation dynamics are instrumental in fuelling the material realisation of scientific-technological projects (e.g. van Lente and Rip, 1998a; Brown et al., 2000; Brown and Michael, 2003; Pollock and Williams, 2010; Parandian et al., 2012; van Lente et al., 2013; Alvial-Palavicino and Konrad, 2019). For instance, van Lente and Rip (1998b) expose how the mobilisation of promises and the subsequent conformation of "shared expectations" constituted the

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[1] As Borup et al. (2006: 286) note, one of the factors underlying the nascent interest in expectations and other anticipatory drivers is the gradual increase and intensity that these have acquired in the shaping of our modern societies. The relationships between the "strategic turn" in scientific-technological practices and anticipation must be read in a context marked by the modes of temporal organisation characteristic of modern and capitalist societies, in which future temporality is exploited as a central resource. For more on how the prevailing *régimes d'historicité* in modernity and our capitalist societies are skewed towards the future, see Beckert (2016); Beckert and Bronk (2018); Hölscher (2018); Ogle (2019).

[2] The range of potential possibilities constrained by scripts are in turn defined as being based on a series of preconfigured representations of technologies' *potential future users*—users who are often idealised and/or subjected to biases during the testing process (Akrich, 1992). For a critique of the idea of "script" see Verbeek (2005).

backbone for the development of mutual positionings around membrane technology and its establishment as a strategic research field.

Heterogeneous coexisting theories of sociotechnical development and change (see Sovacool and Hess, 2017) currently focus on the roles that these and other related prospective elements perform in sociotechnical dynamics. For instance, several authors stress the importance of the mobilisation of "*leitbilder*" or guiding sociotechnical visions: "schemata that represent future objectives and express the means by which these objectives will be realised" (Berkhout, 2006: 302). Mainstream futures representations constituting the development of in-vitro meat clearly reflect this definition: they present the future goal of solving the problems of overproduction and overconsumption of meat while meeting sustainability and animal ethics standards, and position in-vitro meat as the better means by which these goals can (and should) be achieved (Ferrari and Lösch, 2017). Once alignment exists with the future goal embodied in the vision, the vision unfolds its normative power by establishing a technology as the best or necessary solution to achieve that goal, thereby directing and guiding action towards its fulfilment (see also Dierkes et al., 1992; Hellige, 1996; Lösch, 2006; Schneider and Lösch, 2019).

"Sociotechnical imaginaries" is another prominent concept in STS that is tightly connected to the aforementioned ones. Sociotechnical imaginaries are "visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff, 2015: 4). Like *leitbilder*, sociotechnical imaginaries connect social and technological orders while encoding a normative force: they subtly prescribe "how life ought, or ought not, to be lived" (Jasanoff, 2015: 4). Jasanoff and Kim (2009; 2013), for example, have documented how sociotechnical imaginaries on nuclear energy in the United States and South Korea played a crucial role in framing the future benefits and risks of nuclear energy. Sociotechnical imaginaries were instrumental in reinforcing their respective hegemonic ideals of collective life and socio-political orderings (see also Ballo, 2015; Jasanoff and Kim, 2015).[3]

Promises, expectations, visions, and imaginaries are collectively held and co-produced representations about the future that function as STM modulators, nudging sociotechnical systems towards certain paths (see Brown and Michael, 2003: 3; Konrad, 2006: 430). They are simultaneously evolving products and performative producers of sociotechnical realities. These sociotechnical futures colonise belief and value systems as well as the horizons that configure individual and social agency, thereby legitimising programmes of action and mobilising resources (Anderson, 2007; Jasanoff and Kim, 2009: 123; Konrad and Böhle, 2019). Despite being fictitious in character, futures re-arrange "the mass" of sociotechnical systems and provide it with directionality. They enable/constrain the orientation and speed of development of scientific-technological activities by gearing them towards satisfying particular agendas and social orders (Michael, 2000).

The political dynamics of enabling/constraining (or opening-up/closing-down) the directionality and speed of sociotechnical systems through futures can be framed within a model in which the course of history is reconstructed as a space full of possibilities that could have been realised, but few of which finally materialised in what we reconstruct (not without difficulties, tensions, and struggles) as "the past". Past pathways could have taken alternative directions and history can thus be conceived of as a space filled with unrealised opportunities. The present is a contingent outcome of an

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[3] For more case studies in sociotechnical imaginaries, see Volume 50, Issue 4 (2020) of *Social Studies of Science*.

incalculable and highly complex constellation of events and decisions, an outcome that simultaneously enables and constrains future possibilities.

However, how various actors navigate these "presently open possibilities" (i.e. what futures these actors identify, engage, and exploit) varies, and this navigation is anticipatorily mediated by predictive regimes, scripts, visions, expectations, and sociotechnical imaginaries. The representations of the future that coexist in each present act as anticipatory artefacts constraining the set of conceivable normative and pragmatic possibilities on the basis of which diverse actors direct (and give meaning to) their present actions. Anticipatory artefacts close down imagination to a concrete subset of possibilities out of the vast ocean afforded by the present condition (Figure 1).
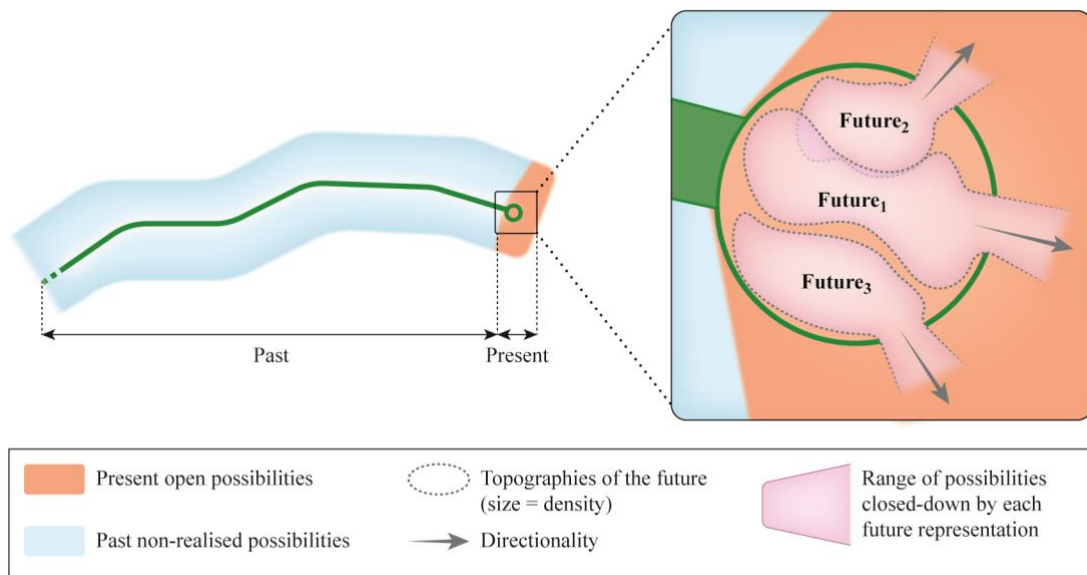
[insert Figure 1.]

Figure 1. Topographies of futures anticipatorily providing directionality to the coevolution of sociotechnical systems. Source: Created by the author.

As Michael (2017) suggests, this landscape of polyphonic topographies of futures is variable. Futures emerge, expand, and decay in a geographically and temporally localised manner, and these mutate over time in accordance with the sociotechnical co-production dynamics that simultaneously sustain and shape their ongoing development. In the struggle for effective STM influence, the different topographies of futures maintain interactions and relations of different kinds and depths between them (e.g. total or partial confrontation, domination, mutual nourishment, neutrality). In this process, the heterogeneous futures' topographies acquire distinct social densities according to 1) the ability of each future to attract/convince and mobilise different actors (e.g. institutions, individuals, organisations), and 2) the positioning of these "future holders" within their network. The density of future representations at any given moment determines the predominant—but not unique—mode of orientation of actions at that moment and thus constitutes the dominant directionality of the STM. The varying choreographies of futures' topographies configure anticipatory dynamics that shape—both in form (how the future is approached) and content (which prescriptive and normative assumptions we attribute to the future)—how future temporality is/should be experienced and lived. Futures representations are thus machineries that anticipatorily

shape (while simultaneously expressing) the politics of future-making; as such, they are never free of socio-political tensions and struggles (Jasanoff, 2020).

The political significance of anticipation has led to normative STS proposals to attend to anticipation as an object of critique and interventive modulation (e.g. Konrad and Alvial Palavicino, 2017; Lösch et al., 2017; Lösch et al., 2019). Proposals such as Constructive Technology Assessment (Schot and Rip, 1997), Vision Assessment (Grin and Grunwald, 2000; Grunwald, 2009), and Hermeneutic Technology Assessment (Grunwald, 2020) are exemplary here. The first proposal strives "to broaden the design of new technologies (and the redesign of old technologies)" (Schot and Rip, 1997: 252) by expanding the concerns and actors considered; that is, it aims to problematise the scripts attached to technologies in design processes. The other two proposals aim to critically assess the sociotechnical meanings that visions and futures convey.[4]

In some instances, these assessment and modulation activities not only have the future as their focus, but are themselves enacted through activities that use representations of the future as a methodological-interventive resource. Following a "*similia et similibus curantur*" rationale (literally, "like cures like"), several STS methodological-interventive initiatives nowadays promote foresight, visioning or futuring techniques as a means to open up the futures that shape STM. In contrast to technocratic uses of futures, the operationalisation of these anticipatory techniques seeks to broaden the concerns considered by nurturing critical reflective capabilities (e.g. Rip and Kulve, 2008; Swierstra et al., 2009; Arnaldi, 2018; Betten et al., 2018). For instance, Selin (2011) operationalises futures scenarios to explore alternative impacts of nanotechnologies, Lehoux et al. (2020) to stimulate moral imagination in health technology, and Withycombe Keeler et al. (2019) to promote "emancipatory" capabilities and sustainable presents.

Examples of recent influential normative proposals that explicitly operationalise anticipation as a non-predictivist and non-technocratic methodological-interventive tool are Anticipatory Governance (Barben et al., 2008; Guston, 2014),[5] Responsible Research and Innovation (European Commission, 2013b; von Schomberg, 2013), Responsible Innovation (Stilgoe et al., 2013), and recent formulations of Technology Assessment (Nazarko, 2017; Grunwald, 2019). All of these initiatives share a common aim of opening-up sociotechnical systems' STM by making the closure processes fostered by futures amenable to interventive modulation.

Anticipation thus appears in STS as: 1) one element of the co-production and coevolution dynamics constituting STM; 2) a phenomenon that should be subject to critical-reflexive consideration; and 3) an interventive method to modulate the prospective structures of contemporary sociotechnical systems and thereby re-shape their STM.

Modal power and the politics of (un)certain futures

Because anticipatory constituents orchestrate the direction of the ongoing construction of sociotechnical realities, they can be understood as mechanisms of power fabrication,

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[4] For an empirical case study where Constructive Technology Assessment and Vision Assessment are integrated, see Roelofsen et al. (2008).

[5] Muiderman et al. (2020), without limiting their review analysis to the field of STS, show how different proposals that promote an "anticipatory" governance (i.e. a governance that involves the methodological-interventive use of futures) coexist. The concepts and forms of engagement with futures that these various "anticipatory" governance proposals promote are variable. Acknowledging this heterogeneity, the use of the term "anticipatory governance" in this article is limited to denote the normative STS proposal/framework presented by Barben et al. (2008).

mobilisation, and enactment. The anticipatory power and relevance of sociotechnical futures and predictivist regimes lies in the functions they perform within the politics of opening-up/closing-down future-making practices in the present: they constrain the focus and scope of the projections that constitute the complex and heterogeneous agential choreographies through which STM is ongoingly co-constructed (Emirbayer and Mische, 1998; Mische, 2009). As blinkers, the anticipatory power of anticipatory artefacts lies in their ability to enframe and limit the envisioning of certain spaces of possibility towards which future-making practices could be directed. If power is fundamentally understood as the capacity of an agent to influence the direction in which reality unfolds, then anticipation can be considered as a subtle mechanism for the fabrication, mobilisation, and execution of power.

This mechanism of power finds its basic *modus operandi* in fixing hypothetical assumptions concerning what is (or should be) considered "(im)plausible" and "(un)desirable" regarding the future, thereby restricting the imagination about practical alternative possibilities towards which action could be oriented in the present. Future representations channel the range of possibilities that animate the direction of ongoing activities and actions that constitute STM, hampering the contemplation of alternatives to guide future-making practices. This capability to fix the domain of what is conceivable as a space of possibilities (i.e. modal spaces) has been specifically labelled by Steve Fuller (2018: 139–149) as "modal power". The heterogeneous future representations widely distributed in the social space form choreographies of anticipatory topological dynamics that engage, fabricate, modulate, and exercise modal power.

Recalling the empirical cases mentioned in the previous section: the promises and expectations of membrane technology, mainstream sustainable visions of in-vitro meat, or the sociotechnical imaginaries of nuclear energy are relevant because they encode empirical and normative stances that fix (or close down) the space of conceivable alternatives: they fix how each technology should be socially and technically framed and valued, as well as the sociotechnical orders that could/should be pursued through such technology. In the same vein, predictivist apparatuses often fix the scope and depth of the issues potentially considered in technology assessment processes (e.g. by focusing on risks and obscuring the required political debate about the purposes and means of technological development). Predictivist modes of framing the futures constrain agents' modal imagination both in terms of considering unpredictable impacts and problematising the processes, purposes, and directions of research and development.

The exercise of modal power through anticipatory practices is at the heart of the political life of opening-up/closing-down STM (see Figure 1). Hughes subtly alluded to how sociotechnical design practices—identified in the previous section as being mediated by anticipatory practices—involve the exercise of what is here framed as "modal power": "One of the primary characteristics of a system builder is the ability to construct or to force unity from diversity, centralization in the face of pluralism, and coherence from chaos. *This construction often involves the destruction of alternative systems*" (Hughes, 1987: 52; emphasis added). The mobilisation of visions, expectations, and imaginaries as well as the confinement of governance articulations to predictivist schemas involve the maintenance/destruction of alternatives by subtle fixations on what can be considered certain or uncertain, what is imaginable and what is not. They inevitably lead to the destruction of alternatives that might nevertheless have been legitimately considered.

The concept of "modal power" offers a tentative account of the mechanisms by which sociotechnical futures and predictive machineries enable/constrain possibilities (i.e. modal spaces) and acquire the performativity and socio-political significance to which STS scholars often allude. It draws attention to the socio-epistemic and socio-material conditions of (un)certainty co-production that sustains, underlies, and enables the performative power of sociotechnical futures. To illuminate the mechanisms that, through representations of the future, mobilise and exercise modal power involves grappling with the politics that underlie the anticipatory fabrication of empirical and normative (un)certainty. Representations of the future that are co-generated and mobilised across social practices generate and conceal, under specific modalities, the spaces of (un)certainty that are detectable and recognisable as such.

Spaces of (un)certainty are established in terms of what is deemed known/unknown, necessary/contingent, desirable/undesirable, etc. By looking to the modes of production and mobilisation of modal power, the focus is not so much (or not only) on how the existence of epistemic ambiguity and uncertainty in contexts of political cleavage raises the possibility of politicisation (e.g. Funtowicz and Ravetz, 1990). Rather, the focus is principally on how certainty is co-constructed and used as a mechanism to depoliticise the possibilities of sociotechnical co-construction open in the present. It is not only a matter of seeing politics in spaces of uncertainty, but also (and primarily) in the very mechanisms of establishing certainty in political arenas—especially when this establishment applies to events that are (relatively) open to (in)occurrence, such as future ones (Rubino, 2000). Restricting the aperture to scrutinising only those spaces that are considered uncertain implies shielding from scrutiny those spaces that are typically considered certain on the basis of purely scientific and technical criteria, as if the production of certainty were completely detached from political values and concerns. Refusing to problematise the politics underlying the mechanisms of fixing certainty entails blindly accepting that the production and fixation of a large part of the assumptions and facts about the future are settled and normative-free.

The co-production of certainty regarding the future has indeed been considered instrumental for domesticating "feral futures", i.e. as a way of neglecting that sociotechnical coevolution can/might take unexpected and different directions (Ramírez and Ravetz, 2011). The mechanisms of the co-production of certainty involve the exercise of modal power insofar as they imply the removal from consideration of "uncomfortable" paths that might challenge the choices (and/or the assumptions on which those choices are based) of those in power. The call to open up modal power, however, is not (and should not be) about entering into a dynamic where "anything goes" (or where everything is considered equally valid). Rather, it is about taking seriously the mechanisms for determining the realms of the "(im)plausible" and the "(un)desirable" by exposing them to discussion and transparency. Key questions in this regard are: Who determines the realm of the "(im)plausible" and/or "(un)desirable"? By what means and on what justificatory grounds? In relation to what problems and purposes? Whose values are taken into account, and why those ones rather than others? The call to open up modal power entails following up and problematising the heterogeneous *contents* and *modes* with which we imagine and approach sociotechnical futures by considering how these are inseparable from our personal and socio-political projects and ambitions; from how we orient our life in the present.[6] It means paying

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[6] The problematisation of futures in terms of *content* refers to the critical engagement with normative and descriptive assumptions underlying future representations. In contrast, problematising the *modes* refers to assessing what kind of engagements with the futures are promoted throughout the mobilisation of these prospective elements: "Do they promote a predictivist relation to the future (i.e. an epistemic approach)?",

close attention to how anticipatory elements such as expectations, visions, and imaginaries, as well as predictivist regimes engender both "substantive" and "formal" bias (Feenberg, 2017) by embodying preferences and meanings about the worlds that *should* (not) be inhabited.

Widening the scope of our blinkers: The negotiation of "(im)plausibility" and "(un)desirability" as a disturbance of modal power

Although anticipation is addressed in STS from the descriptive, critical-normative, and methodological-interventive ideal-typical approaches, these overlap in practice. For example, descriptions that expose how images of the future anticipatorily perform reality could be understood as interventions because they enrich existing understandings of science, technology, and innovation dynamics and thereby aid critique and reflection. Moreover, engagements with futures performed by STS scholars are usually driven by more or less implicit/explicit normative commitments: they are motivated to realise more desirable futures where co-production processes articulate—and are simultaneously articulated by—more self-aware, transparent, and democratic orders (e.g. Stilgoe et al., 2013; Guston, 2014; Jasanoff, 2020).

In this sense, STS scholars not only engage with anticipation by treating it as an object of description, critique or as a means for interventive modulation, but *are themselves embedded in, and contributing to, anticipatory dynamics*. Both the anticipatory dynamics that STS scholars describe, critically assess, and aim to modulate, as well as those that STS scholars mobilise through their normative visions and commitments, are involved in the politics of opening-up/closing-down the present *patterns* and *directions* of STM governance (Stirling, 2008; Fisher, 2019). STS scholars are embroiled in the mobilisations of modal power through futures (Figure 1).

Indeed, recent STS critical-reflexive engagements with prospective elements such as expectations, visions, and imaginaries can be read as an attempt to make visible and disrupt the modal power distributions that these anticipatory artefacts promote. It may be read, in other words, as an attempt to confront the obscuring of alternatives by widening the scope of the anticipatory blinkers through which we experience, imagine, know, and perform the present reality. Motivated by visions of openness, STS scholars typically emphasise the existence of opportunities for manoeuvre by recognising the indeterminate nature of the future and the limited capabilities of human agency to shape—albeit not totally control—the directions and forms of governance (e.g. Guston, 2014; Kuhlmann et al., 2019; Lösch et al., 2019; Jasanoff, 2020). On the one hand, STS descriptive studies on the co-creation and mobilisation of representations of the future such as visions, expectations, and imaginaries trace the anticipatory channels and contents through which modal power is generated, distributed, and executed. On the other hand, STS normative proposals typically point to the need to amplify the space of the "(im)plausible" or "(un)desirable" fixed by such representations through the consideration of alternatives for action and the visibilisation of issues or values that are not contemplated. While, as previously mentioned, both description and normative critique involve intervention to some extent, it is the STS methodological-interventive proposals that explicitly consider anticipatory instruments, or techniques, such as foresight, visioning or futuring practices, as means to enhance reflexivity and support the modulation of modal power.

"Is the future presented as a prefixed space in which human action plays a passive role (i.e. a deterministic approach) or is it presented as an open space to be cared for proactively, not free of struggles and tensions (i.e. a constructive-political approach)?".

Consider, for example, Anticipatory Governance, which uses "foresight" (along with "engagement" and "integration to "collectively imagine, critique, and thereby shape the issues presented by emerging technologies before they become reified" (see Barben et al., 2008: 992)—in other words, to intervene in sociotechnical systems before STM renders their modulation more difficult. In contrast to technocratic and predictivist approaches to the future, foresight is conceived here as a technique which "aims to enrich futures-in-the-making by encouraging and developing reflexivity in the system" (Barben et al., 2008: 986). Responsible Research and Innovation (RRI) is another normative framework championed by the European Commission that relies on "the introduction of a broader foresight" (von Schomberg, 2013: 51). RRI "anticipates and assesses potential implications and societal expectations with regard to research and innovation, with the aim to foster the design of inclusive and sustainable research and innovation" (European Commission, 2013a). Likewise, the Responsible Innovation framework defines anticipation as a central dimension (alongside inclusivity, reflexivity, and responsiveness) aimed at "consider[ing] contingency, what is known, what is likely, what is plausible and what is possible" (Stilgoe et al., 2013: 1570). Technology Assessment advocates have also recently recognised the importance of "enhancing reflexivity *over time*" through anticipation (Grunwald, 2019: 703) in order to democratise technology co-production processes.

These STS-related normative frameworks understand anticipation as an interventive practice that is not primarily focused on looking *into* the future (i.e. generating future presents), but as a socio-epistemic activity aimed at disrupting the mode and content through which we look *to* the future. Far from generating knowledge about what is yet to come, anticipation is used as a tool to make the sociotechnical futures presently considered "(im)plausible" and "(un)desirable" the subject of inclusive discussion, thereby opening-up alternative courses of action that may be more responsive to a broader range of social actors and concerns (Urueña, 2019). By anticipatorily using futures representations, foresight aims to "emancipate" (Withycombe Keeler et al., 2019) "the still, small voices less often heard in the innovation process" (Guston, 2014: 229) in the present. Anticipation is understood in this context as an interventive tool that assists in "taking care of the future through collective stewardship of science and innovation in the present" (Stilgoe et al., 2013: 1570). Anticipation and foresight exercises aim to open up various processes that continuously constitute and close down the STM of sociotechnical systems by setting spaces of (un)certainty. Thus, within the frame provided in this article, anticipation/foresight can be interpreted as a tool for disrupting the modal power allocations which shape and sustain the *momentum* of sociotechnical coevolution processes.

This understanding of anticipation and foresight as tools for the disruption of modal power aligns with recent developments in Futures Studies regarding scenario development and the promotion of capabilities such as futures literacy. For instance, scenario work "seeks to extend the peer community by seriously considering that which had hitherto been unwelcome, politically incorrect, destabilising, and radical, along with that which questions established categories, labels, connotations, roles, sources of legitimacy, and power relations" (Ramírez and Ravetz, 2011: 482). Furthermore, futures literacy proposals aim to 1) identify and/or make visible underlying anticipatory assumptions (including an awareness of the past and present) and 2) deconstruct or challenge the dominant anticipatory assumptions in order to raise new questions, ways of framing, and paths of action in the present (Miller, 2018; Miller and Sandford, 2019).

All of these STS methodological-interventive proposals emphasise the need to disrupt and distribute the modal power that is mobilised and executed on the basis of

representations of the future. It should be emphasised, however, that this disruption can entail different degrees of radicality. The blinkers can be widened to different scopes and in relation to different aspects. The level of radicality could be defined in terms of 1) the domains of research and innovation that are problematised (e.g. impacts/outcomes, processes and/or purposes), 2) the timing of this problematisation (whether *ex ante* to the development of the innovation, *ex dure*, and/or *ex post*), and 3) the actors and concerns involved in this process. For example, only opening-up the debate on the outcomes of an innovation at advanced stages of development may be considered less disruptive or radical than opening-up the debate on its outcomes, processes, and purposes at earlier stages of development. Approaches that appeal to the need for "upstream" engagement aim precisely to increase the radicality of the problematisation of emerging sciences and technologies by engaging multiple voices during the early stages of development, *before the trajectory of these emerging sciences and technologies is fixed and acquires STM* (Wilsdon and Willis, 2004; Rogers-Hayden, 2010). The existence of different gradients of opening-up radicality implies that STS scholars using anticipation as a disruptive tool could benefit from considering what type and degree of disruption they seek to realise, and which actors or futures will be left out or included (and why).

For instance, Withycombe Keeler et al. (2019) argue that foresight exercises can provide "emancipatory" heuristics for disrupting status-quo imaginaries. However, the scenarios-building practice through which that potential is illustrated takes for granted futures where wastewater sensing technologies exist. Similarly, Selin (2011) attempts to promote mechanisms of "negotiating plausibility"—which can be read, in the context of this paper, as an attempt to disrupt modal power—and sets up a series of scenarios where what is problematised is not the political meaning and/or desirability of nanotechnology itself, but rather its concrete applications (i.e. the scenarios subtly assume and reproduce the promises of disruptive development of nanotechnology). When the political dynamics of opening-up/closing-down the present through futures is at stake, the question of which futures are (or should be) considered and in relation to which aspects they are problematised becomes central.

The "negotiation of plausibility" here thus takes on an ambivalent or tension-laden character. On the one hand, the use of plausibility as a methodological criterion and as an epistemic and inferential register enables the futures under consideration to be opened up beyond those that could be identified by standard probabilistic criteria (see Ramírez and Selin, 2014; Urueña, 2019).[7] On the other hand, limiting the scope of discussion to nanotechnology applications requires assuming in advance that nanotechnology is a plausible and desirable general technological project. This second aspect implies closing-down the scope of the "plausibility negotiation" process from a more fundamental debate about the plausibility (or desirability) of nanotechnology itself. Although made in a spirit of openness, these anticipatory interventions may end up reproducing assumptions about the "(im)plausible" and the "(un)desirable". These anticipatory interventions were "not designed to manufacture support (…), but rather to critically reflect on how the technology could develop in unexpected ways" (Withycombe Keeler et al., 2019: 277). However, insofar as these practices take for granted the desirability and plausibility of the emerging technologies under their respective critique and study, they indirectly stabilise the modal power dynamics that seek to benefit and pave the way for their development. Such assumptions restrict the

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[7] The concept of plausibility as an enabling/limiting inferential methodological criterion for foresight and scenario practices is widely discussed in the field of Futures Studies. In this regard, see, for instance, Ramírez and Selin (2014), Fischer and Dannenberg (2021), Schmidt-Scheele (2020), and Urueña (2019).

scope for imagining alternatives and thus reify (even if unintentionally) development paths that could otherwise be problematised.

In addition to examining the scope and depth of the opening created in practice, it is also relevant to ask to what extent the disruption is actually effective. The factors that constitute the STM of sociotechnical systems will also hinder the potential of these methodological-inventive anticipatory practices. Like any form of power, modal power is embedded in and reproduced through complex social fabrics with deep socio-material roots. Institutions, traditions, and sociotechnical forms of organisation will perpetuate and privilege actors who reproduce and ensure their survival.

This implies that anticipation, understood as an interventive methodology aimed at the co-construction of more reflexive, inclusive, and perhaps fairer sociotechnical futures, must itself be located within the sociotechnical context from which it simultaneously emerges and in which it intends to operate. The constitutive dynamics of this context will tend to privilege certain actors and render others invisible. Heterogeneous actors compete to impose their range of considerations regarding the "(im)plausibility" and "(un)desirability" of futures (i.e. to exercise modal power and impose their anticipatory criteria). Only by recognising these socio-material constraints and encouraging their disruption during interventive processes can anticipation become an effective and realistic tool for democratising the politics of future-making.

Conclusions

The future is a battlefield that is continuously settled in the present. But this settlement in the present is in turn influenced by futures images and modes of inhabiting future temporality. STS scholars have devoted particular attention to this phenomenon over the last three decades. STS research has made significant progress in identifying how heterogeneous future-oriented elements shape the direction and speed of science, technology, and innovation co-production dynamics.

Anticipation has been understood in STS as one element of the sociotechnical fabric that shapes (and is simultaneously shaped by) the complex assemblages in which these elements come into play. Whether in the form of predictive-technocratic machineries and scripts embedded in technologies, or as expectations, visions or sociotechnical imaginaries, futures representations modulate the directions and speed of sociotechnical coevolutionary patterns. Following Hughes' terminology: futures constitute heterogeneous anticipatory dynamics that shape the *momentum* of sociotechnical systems.

The cohabiting topographies of futures (e.g. scripts, expectations, visions, sociotechnical imaginaries) and temporal regimes (e.g. prediction-based modes of governance) co-configure (and simultaneously are an expression of) the existing politics of and with futures. These futures function as blinkers which open up/close down possibilities by modulating what counts (or should count) as "(im)plausible" or "(un)desirable" at present. In other words, futures play an important role in the political games of nudging the directionality of sociotechnical development by means of exercising modal power.

As this review article has emphasised, STS scholars are not outsiders to these dynamics. They are embedded within, account for, contribute to, and aim to re-shape these dynamics; usually guided by the aim of pointing to alternative directions and modes of sociotechnical co-production and coevolution. Indeed, this article has argued that STS attempts to open up existing anticipatory dynamics through empirical analysis, critical assessments or methodological-interventive anticipatory practices are primarily

involved and confronted with the description, assessment, and redistribution of modal power. The laudable impetus to democratise future-making practices is operationalized through attempts to open up what is presently considered "(im)plausible" and "(un)desirable". Once again, but in the sphere of futures, STS scholars are concerned with the politics of epistemic and normative (un)certainty.

However, commendable attempts to open up futures always problematise certain aspects and protect others, and therefore can subtly contribute to the stabilisation of certain hegemonic futures. This is the case, for instance, when the socio-political legitimacy of sociotechnical agendas is tacitly shielded from problematisation (e.g. by focusing on impacts while overlooking unresolved issues of social justice). Anticipation can only become a disruptive interventive tool capable of democratising and proposing genuinely alternative futures if it is able to disrupt the socio-material mechanisms that sustain current patterns of (un)certainty fixations through modal power allocations. In this sense, the present article has underscored the need to pay further attention to the conditions and modalities under which these openings occur. Relevant questions in this regard include: Which futures are disrupted, and which stabilised? Whose futures are these? Why these futures and not others?

Author biography

Sergio Urueña is a PhD Candidate 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 operationalising 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. His work has been published in journals such as *NanoEthics* and *Futures*.

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References

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

Akrich M (1992) The De-Scription of Technical Objects. In: Bijker WE and Law J (eds) *Shaping Technology / Building Society. Studies in Sociotechnical Change*. Cambridge, MA and London: The MIT Press, pp.205–224.

Alvial-Palavicino C (2015) The Future as Practice. A Framework to Understand Anticipation in Science and Technology. *TECNOSCIENZA. Italian Journal of Science & Technology Studies* 6(2): 135–172.

Alvial-Palavicino C and Konrad K (2019) The rise of graphene expectations: Anticipatory practices in emergent nanotechnologies. *Futures* 109: 192–202.

Anderson B (2007) Hope for nanotechnology: anticipatory knowledge and the governance of affect. *Area* 39(2): 156–165.

Arnaldi S (2018) Retooling Techno-Moral Scenarios. A Revisited Technique for Exploring Alternative Regimes of Responsibility for Human Enhancement. *NanoEthics* 12(3): 283–300.

Ballo IF (2015) Imagining energy futures: Sociotechnical imaginaries of the future Smart Grid in Norway. *Energy Research & Social Science* 9: 9–20.

Barben D, Fisher E, Selin C, et al. (2008) Anticipatory Governance of Nanotechnology: Foresight, Engagement, and Integration. In: Hackett EJ, Amsterdamska O, Lynch M, et al. (eds) *The Handbook of Science and Technology Studies*. Cambridge, MA: MIT Press, pp.979–1000.

Bechtold U, Fuchs D and Gudowsky N (2017) Imagining socio-technical futures – challenges and opportunities for technology assessment. *Journal of Responsible Innovation* 4(2): 85–99.

Beckert J (2016) *Imagined Futures: Fictional Expectations and Capitalist Dynamics.* Cambridge, MA: Harvard University Press.

Beckert J and Bronk R (2018) *Uncertain Futures: Imaginaries, Narratives, and Calculation in the Economy.* Oxford: Oxford University Press.

Berkhout F (2006) Normative expectations in systems innovation. *Technology Analysis & Strategic Management* 18(3-4): 299–311.

Berube DM (2004) The Rhetoric of Nanotechnology. In: Baird D, Nordmann A and Schummer J (eds) *Discovering the Nanoscale*. Amsterdam: IOS Press, pp.173–192.

Betten AW, Rerimassie V, Broerse JEW, et al. (2018) Constructing future scenarios as a tool to foster responsible research and innovation among future synthetic biologists. *Life Sci Soc Policy* 14(1): 21.

Bijker WE, Hughes T and Pinch T (1987) *The Social Construction of Technological Systems.* Cambridge, MA: The MIT Press.

Bijker WE and Law J (1992) *Shaping Technology / Building Society. Studies in Sociotechnical Change.* Cambridge, MA and London: The MIT Press.

Borup M, Brown N, Konrad K, et al. (2006) The sociology of expectations in science and technology. *Technology Analysis & Strategic Management* 18(3-4): 285–298.

Boslaugh S (2011) Technological Momentum. In: Mulvaney D (ed) *Green Technology: An A-to-Z Guide*. Thousand Oaks, CA: Sage Publications.

Brown N and Michael M (2003) A Sociology of Expectations: Retrospecting Prospects and Prospecting Retrospects. *Technology Analysis & Strategic Management* 15(1): 3–18.

Brown N, Rappert B and Webster A (2000) *Contested Futures: A Sociology of Prospective Techno-Science.* Aldershot and Burlington, VT: Ashgate.

Bryant R and Knight DM (2019) *The Anthropology of the Future.* Cambridge: Cambridge University Press.

Buckner RL, Andrews-Hanna JR and Schacter DL (2008) The Brain's Default Network. *Annals of the New York Academy of Sciences* 1124(1): 1–38.

Callon M (1990) Techno-economic Networks and Irreversibility. *The Sociological Review* 38(1_suppl): 132–161.

Collingridge D (1980) The Social Control of Technology. London: Francis Pinter Ltd.

Dierkes M, Hoffmann U and Marz L (1992) *Leitbild und Technik: zur Entstehung und Steuerung technischer Innovationen.* Berlin: Edition Sigma.

Doll BB, Duncan KD, Simon DA, et al. (2015) Model-based choices involve prospective neural activity. *Nature Neuroscience* 18(5): 767–772.

Emirbayer M and Mische A (1998) What Is Agency? *American Journal of Sociology* 103(4): 962–1023.

European Commission (2013a) *Horizon 2020 — Responsible research & innovation*. Available at: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation (accessed 02/04/221).

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

Feenberg A (2017) Critical theory of technology and STS. *Thesis Eleven* 138(1): 3–12.

Ferrari A and Lösch A (2017) How Smart Grid Meets In Vitro Meat: on Visions as Socio-Epistemic Practices. *NanoEthics* 11(1): 75–91.

Fischer N and Dannenberg S (2021) The social construction of futures: Proposing plausibility as a semiotic approach for Critical Futures Studies. *Futures* 129: 102729.

Fisher E (2019) Governing with ambivalence: The tentative origins of socio-technical integration. *Research Policy* 48(5): 1138–1149.

Fuller S (2018) *Post-Truth: Knowledge As A Power Game.* New York: Anthem Press.

Funtowicz SO and Ravetz JR (1990) *Uncertainty and Quality in Science for Policy.* Dordrecht: Kluwer Academic Publishers.

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

Grunwald A (2009) Vision Assessment Supporting the Governance of Knowledge – the Case of Futuristic Nanotechnology. In: Bechmann G, Gorokhov V and Stehr N (eds) *The Social Integration of Science*. 1 ed. Baden-Baden: Nomos Verlagsgesellschaft mbH & Co. KG, pp.147–170.

Grunwald A (2019) The inherently democratic nature of technology assessment. *Science and Public Policy* 46(5): 702–709.

Grunwald A (2020) The objects of technology assessment. Hermeneutic extension of consequentialist reasoning. *Journal of Responsible Innovation* 7(1): 96–112.

Guston DH (2014) Understanding 'anticipatory governance'. *Social Studies of Science* 44(2): 218–242.

Hanseth O, Monteiro E and Hatling M (1996) Developing Information Infrastructure: The Tension Between Standardization and Flexibility. *Science, Technology, & Human Values* 21(4): 407–426.

Hanson VL (2011) Envisioning Ethical Nanotechnology: The Rhetorical Role of Visions in Postponing Societal and Ethical Implications Research. *Science as Culture* 20(1): 1–36.

Hartog F (2003) *Régimes d'historicité: présentisme et expériences du temps.* Paris: Éditions du Seuil.

Hellige HD (1996) *Technikleitbilder auf dem Prüfstand : Leitbild-Assessment aus Sicht der Informatik- und Computergeschichte.* Berlin: Edition Sigma.

Hölscher L (2018) Future-Thinking: A Historical Perspective. In: Oettingen G, Sevincer AT and Gollwitzer PM (eds) *The Psychology of Thinking about the Future*. New York, London: The Guildford Press.

Hughes TP (1969) Technological momentum in history: hydrogenation in Germany, 1893–1933. *Past & Present* 44(1): 106–132.

Hughes TP (1983) *Networks of Power: Electrification in Western Society, 1880–1930.* Baltimore, MD and London: Johns Hopkins University Press.

Hughes TP (1987) The Evolution of Large Technological Systems. In: Bijker WE, Hughes T and Pinch T (eds). Cambridge, MA: The MIT Press, pp.51–82.

Hughes TP (1994) Technological Momentum. In: Smith MR and Marx L (eds) *Does Technology Drive History? The Dilemma of Technological Determinism*. Cambridge, MA: The MIT Press, pp.101–103.

Jasanoff S (2003) Technologies of Humility: Citizen Participation in Governing Science. *Minerva* 41(3): 223–244.

Jasanoff S (2015) Future Imperfect: Science, Technology, and the Imaginations of Modernity. In: Jasanoff S and Kim S-H (eds) *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*. Chicago: University of Chicago Press, pp.1–33.

Jasanoff S (2016) *The Ethics of Invention: Technology and the Human Future.* New York and London: W. W. Norton & Company.

Jasanoff S (2020) Imagined worlds: The politics of future-making in the twenty-first century. In: Wenger A, Jasper U and Dunn Cavelty M (eds) *The Politics and Science of Prevision: Governing and Probing the Future*. London: Routledge, pp.27–44.

Jasanoff S and Kim S-H (2009) Containing the Atom: Sociotechnical Imaginaries and Nuclear Power in the United States and South Korea. *Minerva* 47(2): 119–146.

Jasanoff S and Kim S-H (2013) Sociotechnical Imaginaries and National Energy Policies. *Science as Culture* 22(2): 189–196.

Jasanoff S and Kim S-H (2015) *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power.* Chicago: University of Chicago Press.

Konrad K (2006) The social dynamics of expectations: The interaction of collective and actor-specific expectations on electronic commerce and interactive television. *Technology Analysis & Strategic Management* 18(3-4): 429–444.

Konrad K and Alvial Palavicino C (2017) Evolving Patterns of Governance of, and by, Expectations: The Graphene Hype Wave. In: Bowman DM, Stokes E and Rip A (eds) *Embedding New Technologies into Society: A Regulatory, Ethical and Societal Perspective*. Singapore: Pan Stanford, pp.187–218.

Konrad K and Böhle K (2019) Socio-technical futures and the governance of innovation processes—An introduction to the special issue. *Futures* 109: 101–107.

Konrad KE, van Lente H, Groves C, et al. (2016) Performing and Governing the Future in Science and Technology. In: Felt U, Fouche R, Miller CA, et al. (eds) *The Handbook of Science and Technology Studies*. Cambridge, MA: MIT Press, pp.465–493.

Koselleck R (2004) *Futures Past: On the Semantics of Historical Time.* New York: Columbia University Press.

Kuhlmann S, Stegmaier P and Konrad K (2019) The tentative governance of emerging science and technology—A conceptual introduction. *Research Policy* 48(5): 1091–1097.

Latour B (1992) Where Are the Missing Masses? The Sociology of a Few Mundane Artifacts. In: Bijker WE and Law J (eds) *Shaping Technology / Building Society*.

Studies in Sociotechnical Change. Cambridge, MA and London: The MIT Press, pp.225–258.

Lehoux P, Miller FA and Williams-Jones B (2020) Anticipatory governance and moral imagination: Methodological insights from a scenario-based public deliberation study. *Technological Forecasting and Social Change* 151: 119800.

Lösch A (2006) Anticipating the futures of nanotechnology: Visionary images as means of communication. *Technology Analysis & Strategic Management* 18(3-4): 393–409.

Lösch A, Grunwald A, Meister M, et al. (2019) *Socio-Technical Futures Shaping the Present. Empirical Examples and Analytical Challenges.* Wiesbaden: Springer.

Lösch A, Heil R and Schneider C (2017) Responsibilization through visions. *Journal of Responsible Innovation* 4(2): 138–156.

Mallard G and Lakoff A (2011) How Claims to Know the Future are Used to Understand the Present. Techniques of Prospection in the Field of National Security. In: Lamont M, Gross N and Camic C (eds) *Social Knowledge in the Making*. Chicago, MI and London: University of Chicago Press, pp.339–377.

Michael M (2000) Futures of the Present: From Performativity to Prehension. In: Brown N, Rappert B and Webster A (eds) *Contested Futures: A Sociology of Prospective Techno-Science*. Aldershot & Burlington, VT: Ashgate, pp.21–39.

Michael M (2017) Enacting Big Futures, Little Futures: Toward an ecology of futures. *The Sociological Review* 65(3): 509–524.

Miller R (2018) *Transforming the Future: Anticipation in the 21st Century.* London: Routledge.

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

Misa TJ (1992) Controversy and Closure in Technological Change: Constructing "Steel". In: Bijker WE and Law J (eds) *Shaping Technology / Building Society: Studies in Sociotechnical Change*. Cambridge, MA and London: The MIT Press, pp.109–139.

Misa TJ (1994) Retrieving Sociotechnical Change from Technological Determinism. In: Smith MR and Marx L (eds) *Does Technology Drive History? The Dilemma of Technological Determinism*. Cambridge, MA: The MIT Press, pp.115–141.

Mische A (2009) Projects and Possibilities: Researching Futures in Action. *Sociological Forum* 24(3): 694–704.

Mische A (2014) Measuring futures in action: projective grammars in the Rio + 20 debates. *Theory and Society* 43(3): 437–464.

Muiderman K, Gupta A, Vervoort J, et al. (2020) Four approaches to anticipatory climate governance: Different conceptions of the future and implications for the present. *WIREs Climate Change* 11(6): e673.

Nazarko Ł (2017) Future-Oriented Technology Assessment. *Procedia Engineering* 182: 504–509.

Nowotny H, Scott PB and Gibbons MT (2001) *Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty.* Cambridge: Polity Press.

Nye DE (2006) *Technology Matters: Questions to Live With.* Cambridge, MA and London: The MIT Press.

Ogle V (2019) Time, Temporality and the History of Capitalism. *Past & Present* 243(1): 312–327.

Parandian A, Rip A and Te Kulve H (2012) Dual dynamics of promises, and waiting games around emerging nanotechnologies. *Technology Analysis & Strategic Management* 24(6): 565–582.

Poli R (2017) *Introduction to Anticipation Studies.* Cham: Springer.

Poli R and Valerio M (2019) *Anticipation, Agency and Complexity.* Cham: Springer.

Pollock N and Williams R (2010) The business of expectations: How promissory organizations shape technology and innovation. *Social Studies of Science* 40(4): 525–548.

Povlock PA (2016) *Environmental Ethics and The Electric Power Grid: A Case for Technological Momentum*. Salve Regina University, Newport, RI.

Ramírez R and Ravetz J (2011) Feral futures: Zen and aesthetics. *Futures* 43(4): 478–487.

Ramírez R and Selin C (2014) Plausibility and probability in scenario planning. *Foresight* 16(1): 54–74.

Rip A and Kulve Ht (2008) Constructive Technology Assessment and Socio-Technical Scenarios. In: Fisher E, Selin C and Wetmore JM (eds) *The Yearbook of Nanotechnology in Society, Volume I: Presenting Futures*. Dordrecht: Springer Netherlands, pp.49–70.

Roelofsen A, Broerse JEW, de Cock Buning T, et al. (2008) Exploring the future of ecological genomics: Integrating CTA with vision assessment. *Technological Forecasting and Social Change* 75(3): 334–355.

Rogers-Hayden T (2010) Upstream Engagement. In: Priest SH (ed) *Encyclopedia of science and technology communication*. Thousand Oaks, CA: SAGE Publications, Inc., pp.926–928.

Rubino CA (2000) The Politics of Certainty: Conceptions of Science in an Age of Uncertainty. *Science and Engineering Ethics* 6(4): 499–508.

Sarewitz DR, Pielke RA and Byerly R (2000) *Prediction: Science, Decision Making, and the Future of Nature.* Washington, D.C.: Island Press.

Schmidt-Scheele R (2020) *The Plausibility of Future Scenarios: Conceptualising an Unexplored Criterion in Scenario Planning.* Bielefeld: transcript Verlag.

Schneider C and Lösch A (2019) Visions in assemblages: Future-making and governance in FabLabs. *Futures* 109: 203–212.

Schot J and Rip A (1997) The past and future of constructive technology assessment. *Technological Forecasting and Social Change* 54(2): 251–268.

Seligman MEP, Railton P, Baumeister RF, et al. (2016) *Homo Prospectus.* Oxford and New York, NY: Oxford University Press.

Selin C (2006) Time Matters: Temporal harmony and dissonance in nanotechnology networks. *Time & Society* 15(1): 121–139.

Selin C (2007) Expectations and the Emergence of Nanotechnology. *Science, Technology, & Human Values* 32(2): 196–220.

Selin C (2011) Negotiating Plausibility: Intervening in the Future of Nanotechnology. *Science and Engineering Ethics* 17(4): 723–737.

Sovacool BK and Hess DJ (2017) Ordering theories: Typologies and conceptual frameworks for sociotechnical change. *Social Studies of Science* 47(5): 703–750.

Stilgoe J, Owen R and Macnaghten P (2013) Developing a framework for responsible innovation. *Research Policy* 42(9): 1568–1580.

Stirling A (2008) "Opening Up" and "Closing Down":Power, Participation, and Pluralism in the Social Appraisal of Technology. *Science, Technology, & Human Values* 33(2): 262–294.

Swierstra T, Stemerding D and Boenink M (2009) Exploring Techno-Moral Change: The Case of the ObesityPill. In: Sollie P and Düwell M (eds) *Evaluating New Technologies*. Dordrecht: Springer, pp.119–138.

Urueña S (2019) Understanding "plausibility": A relational approach to the anticipatory heuristics of future scenarios. *Futures* 111: 15–25.

van Lente H and Rip A (1998a) Expectations in Technological Developments: An Example of Prospective Structures to be Filled in by Agency. In: Disco C and van der Meulen B (eds) *Getting New Technologies Together: Studies in Making Sociotechnical Order*. Berlin and New York, NY: Walter de Gruyter, pp.203–230.

van Lente H and Rip A (1998b) The Rise of Membrane Technology: From Rhetorics to Social Reality. *Social Studies of Science* 28(2): 221–254.

van Lente H, Spitters C and Peine A (2013) Comparing technological hype cycles: Towards a theory. *Technological Forecasting and Social Change* 80(8): 1615–1628.

Verbeek P-PCC (2005) Artifacts and Attachment: A Post-Script Philosophy of Mediation. In: Habers H (ed) *Inside the Politics of Technology: Agency and Normativity in the Co-Production of Technology and Society*. Amsterdam: Amsterdam University Press.

Vermaas P, Kroes P, van de Poel I, et al. (2011) *A Philosophy of Technology - From Technical Artefacts to Sociotechnical Systems*. San Rafael, CA: Morgan & Claypool.

von Schomberg R (2013) A Vision of Responsible Research and Innovation. In: Owen R, Bessant JR and Heintz M (eds) *Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society*. Chichester: Wiley, pp.51–74.

Wang P and Burton Swanson E (2008) Customer relationship management as advertised: Exploiting and sustaining technological momentum. *Information Technology & People* 21(4): 323–349.

Wilsdon J and Willis R (2004) *See through Science: Why public engagement needs to move upstream*. London: Demos.

Winner L (1980) Do Artifacts Have Politics? *Daedalus* 109(1): 121–136.

Withycombe Keeler L, Bernstein MJ and Selin C (2019) Intervening Through Futures for Sustainable Presents: Scenarios, Sustainability, and Responsible Research and Innovation. In: Lösch A, Grunwald A, Meister M, et al. (eds) *Socio-Technical Futures Shaping the Present. Empirical Examples and Analytical Challenges*. Wiesbaden: Springer VS, pp.255–282.